



# Flexible floor systems

The effectiveness of flexibility measures in improving the circularity of building components

Master thesis

Lisa van Iperen

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Final version



# Flexible floor systems

The effectiveness of flexibility measures in improving the circularity of building components

By

Lisa Irene van Iperen

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## Preface

Before you lies the thesis “*Flexible floor systems: The effectiveness of flexibility measures in improving the circularity of building components*”. This thesis has been written in conclusion of my master studies in Building Engineering with the specialisation of Structural Design at the Faculty of Civil Engineering and Geosciences of the Delft University of Technology. I was engaged in the researching and writing of this thesis from December 2020 to August 2021, in collaboration with the Delft University of Technology and Van Wijnen Engineering Dordrecht.

During my studies, I have always enjoyed and been interested in the connection between the theory as taught in university and how it is put into practice in full-size building projects. In addition, I have been interested in sustainability for a long time. I try to make conscious sustainable decisions in my own everyday life and I would like to do the same in my professional domain. That is why, at the start of my thesis journey, I went looking for a thesis topic that would provide a practical angle to the topics of sustainability and circularity in the building industry. Based on this ambition, my research question was formulated together with Brenda Goedhart and Robbert-Jan Meijers of Van Wijnen Engineering.

I would like to thank Brenda and Robbert-Jan for their active participation in my search for a research topic, for giving me a place within Van Wijnen Engineering, and for making their network available to me. I would like to thank Brenda specifically for her guidance and feedback regarding the academic underpinning of my research and Robbert-Jan for taking me along in the building process of residential buildings and brainstorming with me about the possibilities and impossibilities of floor design. I would also like to express my gratitude to the members of my graduation committee from the Delft University of Technology for thinking along with me, both on the topic of my thesis and the organisational process around it, and helping me bring my thesis to a successful conclusion. I want to thank Roel Schipper, as the chair of my committee, for guarding my progress and having my and my research's best interest at heart during our meetings. I would like to thank Marco Schuurman for his realistic and practical views and advice on my research topic and process, and Wenjun Cao for her input regarding circularity assessments and for encouraging me to work on an extended abstract and a journal paper based on my research. In addition, I would like to thank my colleagues at Van Wijnen Engineering Dordrecht for their welcoming attitudes towards me and my research and for providing me with a pleasant working environment. I would specifically like to thank Esther Brouwer, who was actively involved in the initial phases of my thesis and gave me advice and insights based on her own experiences in researching and writing a master thesis. I also wish to thank all of the interviewees, who remain anonymous, for taking the time to answer my questions and providing me with an insight into the different disciplines of the building industry.

Finally, I would like to express my gratitude to my family and friends who supported me throughout the writing of my thesis. I want to thank my friends for our many walking breaks that got me out of the house and away from my laptop during the Corona pandemic and allowing me to talk through my process or take my mind off my thesis when I needed to. I also want to thank my housemates, whose company I especially appreciated during the global pandemic, for all the times we relaxed on the couch together at the end of a long day. I want to extend special thanks to my parents for igniting my interest in buildings and for their efforts to remove any obstacle out of my way so I could fully focus on writing and researching my thesis.

I hope you enjoy reading my thesis,

Lisa van Iperen

Delft, August 1<sup>st</sup>, 2021

## Abstract

The environmental strain and depletion of natural resources caused by the current economic system could be reduced through the transition to a more circular economy, based on regenerative use of resources, where materials are kept in use for as long as possible and their value is retained (Cheshire, 2016; Ellen MacArthur Foundation, 2013; European Commission, 2015; Geldermans & Jacobson, 2015). The building industry has an important part to play in this transition, as it is a heavy user of raw materials and a large producer of construction and demolition waste (Merrild et al., 2016; Rijksoverheid, 2016). The circularity of the building industry can be improved by reducing waste production and preventing the need for additional material input by increasing the service life of existing structures and components (Platform CB'23, 2020; Rijksoverheid, 2018).

The service life of buildings and building components is usually limited by the frequently changing user demands and their inability to adapt to new requirements (Blok & van Herwijnen, 2005; Durmisevic, 2006; Landman, 2016). In Dutch residential buildings, the building services are often cast into the floors, creating one fixed element (Durmisevic, 2006; Landman, 2016). As a result of this integration, adaptation to changing technical requirements or different spatial topologies results in damage or even demolition of the load-bearing floor, reducing the overall service life of the floor system (Brand, 1994; Durmisevic, 2006). A way to remedy this is by designing the floor systems to be able to adapt to changing circumstances and user requirements through flexible design (Geraedts, 1996; Gijsbers, 2011; Schmidt et al., 2011). This way, flexible design could provide a practical approach to improve the circularity of building components such as floor systems. This leads to the main research question of this thesis: *“To what extent can flexibility measures improve the circularity of prefabricated floor systems in residential buildings?”*

The main research question was addressed in two parts. First, the theoretical framework for the research was compiled, then the theory was put into a practical context through a case study. As part of the theoretical framework, a literature study was done into the factors that influence the flexibility of design, existing designs for flexible floor systems, and existing assessment methods for the circularity and flexibility of building components. In addition, interviews were held with people involved in different parts of the decision and design process of building projects to identify possible opportunities and challenges for the implementation of flexible design of floor systems.

As a result of the research into the factors that influence the flexibility of design, seven technical characteristics were identified that should be included in the design process to accomplish flexibility of design. These technical characteristics of flexible design are accessibility, durability, independence, integration, interface simplicity, overcapacity, and standardisation. Accessibility indicates the possibility to access components that need to be adapted without hindrance from other components. Durability regards the capacity of a material or system to continue to be useful after an extended period of time and usage. Independence concerns the technical separation of parts with different service lives and functions, while integration indicates the technical coupling of parts that are unlikely to ever be adapted separately. Interface simplicity requires the use of uncomplicated mechanical connections between elements to allow for easy disconnection. Overcapacity indicates the ability of a design to accommodate higher technical specifications than initially required and allows for flexibility in the application of the design in different functions. Finally, standardisation regards the use of the same components size and construction details throughout the design to ensure compatibility between different parts.

From the interviews, it became apparent that flexible design provides opportunities for both the clients and the building industry itself. Flexible design offers clients the possibility to adapt their buildings to changing circumstances and requirements and plays into the growing interest and willingness of clients to invest in sustainable alternatives. It is expected that the opportunities regarding adaptability to future developments and residual value are especially interesting to professional investors. For the building industry, flexible design can have a positive impact on the efficiency of the collaboration between different disciplines in the design process. Other opportunities for the building industry lie with reduced failure costs and the possibility to increase the standardisation of building components. The main challenges for the adaptation of flexible design in practice, as identified through the interviews, are the conservative nature of the building industry and the possible cost increase of building projects as a result of the use of a novel floor system.

The literature study into the existing flexible floor designs showed that two types of flexible floor systems can be identified. The first type has the building services incorporated within the structural height of the floor and can be further subdivided into floor systems that are variations of the hollow core slab with grooves through which pipes can be laid and floor systems with a hollow space within the structural height of the floor for the placement of building services. The second type concerns systems where the building services are separated from the structural floor and the building services are either placed on top or below the load-bearing floor.

Through the literature study, a variety of circularity assessment methods was identified. Based on the availability of the full method and the applicability on a building component level, the Building Circularity Indicator method was found to be the most relevant for this thesis. No suitable method was found for the flexibility assessment of building components. Therefore, a new flexibility assessment method was developed based on the seven technical characteristics of flexible design.

As part of the case study, the building code and stakeholder requirements for the design of a floor system were compiled and the existing flexible floor designs, as well as some traditionally used floor systems, were assessed on their circularity and flexibility to identify what characteristics of the floor designs contribute to their circularity and flexibility and where there was room for improvement. This was used as input for the development of a new flexible floor system. Several design concepts for flexible floor systems were worked out based on the incorporation of the technical characteristics of flexible design and with cost considerations in mind. The design concepts were developed, verified, adapted, and at times discarded, based on the building code and stakeholder requirements. The resulting designs are two versions of a prestressed ribbed concrete floor element. The ribs are placed at the top of the concrete slab. Between the ribs, there is space for the placement of building services and the ribs contain openings for the routing of pipes and cables. The gaps between the ribs are covered with panels, which remain removable for accessibility of the building services, and are filled with a loose granulate material for sound insulation.

The developed floor systems were assessed on their circularity and flexibility and compared to the existing flexible floor designs and traditional floor systems. This comparison showed that the developed floor systems have the highest flexibility score of all floor systems included in the comparison and also have circularity scores that are among the highest. The high circularity score as a result of a design based on flexibility and cost considerations indicates that the circularity of a floor system is improved by the inclusion of flexibility measures in the design. When looking at all the floor systems included in the comparison, a significant positive correlation between the circularity and flexibility scores of the floor systems was found. In conclusion, the implementation of flexibility measures can improve the circularity of prefabricated floor systems in residential buildings.

## Samenvatting

De belasting van het milieu en de uitputting van grondstoffen als gevolg van het huidige economische systeem kunnen worden gereduceerd door een transitie naar een meer circulaire economie, waarbij materialen langer in gebruik blijven en zo lang mogelijk hun waarde behouden (Cheshire, 2016; Ellen MacArthur Foundation, 2013; European Commission, 2015; Geldermans & Jacobson, 2015). De bouwsector speelt een belangrijke rol in deze transitie, aangezien zij een grootverbruiker van grondstoffen is en een grote producent van bouw- en sloopafval (Merrild et al., 2016; Rijksoverheid, 2016). De circulariteit van de bouw kan worden verbeterd door de afvalproductie en de vraag naar nieuwe grondstoffen te verminderen door de levensduur van bestaande constructies en bouwcomponenten te verlengen (Platform CB'23, 2020; Rijksoverheid, 2018).

De levensduur van gebouwen en bouwcomponenten wordt meestal beperkt door de regelmatig veranderende gebruikerseisen en het onvermogen van de gebouwen en hun componenten om zich hieraan aan te passen (Blok & van Herwijnen, 2005; Durmisevic, 2006; Landman, 2016). In Nederlandse woongebouwen worden installaties vaak in de vloer gestort, waardoor er één vast element ontstaat (Durmisevic, 2006; Landman, 2016). Door deze vaste integratie resulteren aanpassingen aan veranderende technische eisen of een nieuwe ruimtelijke indeling in beschadiging of zelfs de sloop van de dragende vloer, wat de totale levensduur van het vloersysteem beperkt (Brand, 1994; Durmisevic, 2006). Dit kan worden verholpen door de vloeren zo te ontwerpen dat ze aanpasbaar zijn aan veranderende omstandigheden en gebruikerseisen doormiddel van een flexibel ontwerp (Geraedts, 1996; Gijsbers, 2011; Schmidt et al., 2011). Op deze manier kan flexibel ontwerpen een praktische aanpak bieden om de circulariteit van bouwcomponenten zoals vloersystemen te verbeteren. Dit leidt tot de hoofdonderzoeksvraag van deze thesis: *“In hoeverre kunnen flexibilitaatsmaatregelen de circulariteit van geprefabriceerde vloersystemen in woongebouwen verbeteren?”*

De hoofdonderzoeksvraag is in twee delen behandeld. Eerst is het theoretisch kader voor het onderzoek opgesteld, daarna is de theorie doormiddel van een casestudy in een praktische context geplaatst. Als onderdeel van het theoretische kader, is een literatuurstudie gedaan naar de factoren die de flexibiliteit van een ontwerp beïnvloeden, bestaande ontwerpen voor flexibele vloersystemen, en bestaande beoordelingsmethoden voor de circulariteit en flexibiliteit van bouwcomponenten. Daarnaast zijn er interviews gehouden met mensen die betrokken zijn bij verschillende delen van het beslissings- en ontwerpproces van bouwprojecten om mogelijke kansen en uitdagingen voor de implementatie van flexibel ontworpen vloersystemen te identificeren.

Uit het literatuuronderzoek naar de factoren die de flexibiliteit van een ontwerp beïnvloeden, zijn zeven technische kenmerken naar voren gekomen die meegenomen behoren te worden in het ontwerpproces om een flexibel ontwerp te realiseren. Deze zeven technische kenmerken van een flexibel ontwerp zijn bereikbaarheid, duurzaamheid, onafhankelijkheid, integratie, connectie eenvoud, overcapaciteit, en standaardisatie. Bereikbaarheid duidt op de mogelijkheid om onderdelen die moeten worden aangepast te bereiken zonder hinder van andere componenten. Duurzaamheid heeft betrekking op het vermogen van een materiaal of systeem om bruikbaar te blijven na een langer tijd van gebruik. Onafhankelijkheid betreft de technische ontkoppeling van delen met verschillende levensduren en functies, terwijl integratie de technische koppeling van delen waarvan aannemelijk is dat deze nooit afzonderlijk aangepast zullen worden betreft. Connectie eenvoud vereist het gebruik van simpele mechanische connecties tussen verschillende elementen voor een gemakkelijke ontkoppeling. Overcapaciteit duidt op het vermogen van een ontwerp om hogere technische specificaties aan te kunnen dan aanvankelijk vereist en zorgt voor flexibiliteit in de toepassing van het ontwerp binnen verschillende functies. Ten slotte heeft standaardisatie betrekking op het gebruik van dezelfde componentengrootte en constructiedetails binnen het gehele ontwerp om compatibiliteit tussen verschillende onderdelen te verzekeren.

Uit de interviews bleek dat flexibel ontwerpen kansen biedt voor zowel de opdrachtgever als de bouwsector zelf. Flexibel ontwerpen biedt opdrachtgevers de mogelijkheid om hun gebouwen aan te passen aan veranderende omstandigheden en eisen en speelt in op de groeiende interesse en bereidheid van opdrachtgevers om te investeren in duurzame alternatieven. De verwachting is dat vooral de kansen met betrekking tot aanpasbaarheid aan toekomstige ontwikkelingen en restwaarde interessant zijn voor professionele beleggers. Voor de bouwsector kan flexibel ontwerpen een positief effect hebben op de efficiëntie van de samenwerking tussen verschillende disciplines in het ontwerpproces. Ook liggen er kansen voor de bouw om de faalkosten te verlagen en de standaardisatie

van bouwcomponenten te vergroten. De belangrijkste uitdagingen voor het toepassen van flexibel ontwerpen in de praktijk, die naar voren zijn gekomen uit de interviews, zijn het conservatieve karakter van de bouwsector en de mogelijke kostenstijging van bouwprojecten als gevolg van het gebruik van een nieuw vloersysteem.

Uit het literatuuronderzoek naar bestaande ontwerpen voor flexibele vloersystemen is gebleken dat er onderscheid kan worden gemaakt tussen twee verschillende typen. Bij het eerste type zijn de installaties verwerkt binnen de constructieve hoogte van de vloer. Dit type kan verder worden onderverdeeld in variaties van de kanaalplaatvloer met sleuven waardoor pijpen kunnen worden gelegd en vloeren met een holle ruimte binnen de constructieve hoogte van de vloer waarin installaties geplaatst kunnen worden. Het tweede type betreft systemen waarbij de installaties zijn gescheiden van de dragende vloer en deze bovenop of onder de dragende vloer geplaatst worden.

Doormiddel van het literatuuronderzoek zijn er verschillende bestaande circulariteitsbeoordelingsmethodes geïdentificeerd. Op basis van beschikbaarheid van de volledige methode en toepasbaarheid op bouwcomponentenniveau is bepaald dat de Building Circularity Indicator-methode het meest geschikt was voor toepassing in dit onderzoek. Er is geen geschikte methode gevonden voor de beoordeling van de flexibiliteit van bouwcomponenten. Daarom is een nieuwe flexibiliteitsbeoordelingsmethode ontwikkeld gebaseerd op de zeven technische kenmerken van een flexibel ontwerp.

Als onderdeel van de casestudy zijn de eisen vanuit de bouwvoorschriften en de stakeholders voor het ontwerp van een vloersysteem opgesteld en zijn de bestaande flexibele vloersystemen, evenals enkele traditioneel gebruikte vloersystemen, beoordeeld op hun circulariteit en flexibiliteit om te bepalen welke kenmerken van de vloerontwerpen bijdragen aan hun circulariteit en flexibiliteit en waar er ruimte is voor verbetering. Dit is gebruikt als input voor de ontwikkeling van een nieuw flexibel vloersysteem. Diverse ontwerpconcepten voor een flexibele vloer zijn uitgewerkt op basis van de technische kenmerken van flexibel ontwerpen en met in achtneming van kostenoverwegingen. De resulterende ontwerpen zijn twee versies van een voorgespannen geribde betonnen vloerelement. De ribben zitten aan de bovenkant van de betonplaat. Tussen de ribben is er ruimte voor het plaatsen van de installaties en het trekken van leidingen en kabels. De gaten tussen de ribben worden afgedekt met panelen, die wegneembaar blijven voor de bereikbaarheid van de installaties, en worden opgevuld met een los granulaatmateriaal ter behoefte van de geluidsisolatie.

De ontwikkelde vloersystemen zijn beoordeeld op circulariteit en flexibiliteit en vergeleken met de bestaande flexibele vloerontwerpen en de traditionele vloersystemen. Deze vergelijking laat zien dat de ontwikkelde vloersystemen de hoogste flexibiliteitsscore hebben van alle vloersystemen die meegenomen zijn in de vergelijking en daarbij ook circulariteitsscores hebben die tot de hoogste behoren. De hoge circulariteitsscores als resultaat van een ontwerp op basis van flexibiliteit- en kostenoverwegingen laat zien dat de circulariteit van een vloersysteem wordt verbeterd door het meenemen van flexibiliteitsmaatregelen in het ontwerp. Bij de vloersystemen die meegenomen zijn in de vergelijking is een significante positieve correlatie gevonden tussen de circulariteits- en flexibiliteitsscores van de vloersystemen. In conclusie, de implementatie van flexibiliteitsmaatregelen kan de circulariteit van prefab vloersystemen in woongebouwen verbeteren.



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## List of acronyms

|            |                                |
|------------|--------------------------------|
| <b>AHP</b> | Analytical Hierarchy Process   |
| <b>BCI</b> | Building Circularity Indicator |
| <b>BOM</b> | Bill Of Materials              |

|             |                                                        |
|-------------|--------------------------------------------------------|
| <b>CEI</b>  | Circularity Economy Index                              |
| <b>CEIP</b> | Circular Economy Indicator Prototype                   |
| <b>CSA</b>  | Comparative Selection method for Adaptability measures |
| <b>ECI</b>  | Element Circularity Index                              |
| <b>EPD</b>  | Environmental Economy Index                            |
| <b>KCC</b>  | Kingfisher Circularity Calculator                      |
| <b>LCA</b>  | Life Cycle Assessment                                  |
| <b>MCI</b>  | Material Circularity Indicator                         |
| <b>MFA</b>  | Material Flow Analysis                                 |
| <b>PBCI</b> | Predictive Building Circularity Indicator              |
| <b>PCI</b>  | Product Circularity Indicator                          |
| <b>SCI</b>  | System Circularity Indicator                           |
| <b>TC</b>   | Transformation Capacity                                |

## Glossary

|                           |                                                                                                                                 |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| <b>Accessibility</b>      | Access to the component that needs to be adapted without hindrance from other components.                                       |
| <b>Active flexibility</b> | The ability of a product to be adapted to facilitate spatial or functional flexibility.                                         |
| <b>Adaptability</b>       | The capacity of a building component to take on physical and lasting changes without consequences to other building components. |
| <b>Building services</b>  | The electrical, plumbing and mechanical systems distributed within a building                                                   |
| <b>Circular economy</b>   | An economic model in which products are designed to retain their value and cycle back into use at the end of their life.        |
| <b>Demountability</b>     | The capacity to deconstruct the components from the building and deconstruct components into their constituents.                |

|                               |                                                                                                                                                                                                                      |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Durability</b>             | The capacity of materials and systems to continue to be useful after an extended period of time and usage.                                                                                                           |
| <b>Economical lifespan</b>    | The period of time during which the future revenue of a building is higher than the future costs.                                                                                                                    |
| <b>Flexibility</b>            | The capacity of a building or building component to adapt to changing circumstances and user requirements.                                                                                                           |
| <b>Floor system</b>           | The assembly of all the components that make up a floor, including its structural function, its horizontal separating function, and the housing of the building services that ought to be incorporated in the floor. |
| <b>Functional flexibility</b> | Flexibility that enables the change of use of a space without changing its spatial structure.                                                                                                                        |
| <b>Functional lifespan</b>    | The period of time during which the functional requirements of the users are still met by the building                                                                                                               |
| <b>Independence</b>           | The technical separation of elements of different service lives and functions.                                                                                                                                       |
| <b>Integration</b>            | The technical coupling of components that will never be adapted separately.                                                                                                                                          |
| <b>Interface simplicity</b>   | The use of uncomplicated mechanical connections between elements.                                                                                                                                                    |
| <b>Modularity</b>             | The consistent use of matching building blocks that can form into a larger component or system.                                                                                                                      |
| <b>Movability</b>             | The possibility to place a building component at a new location.                                                                                                                                                     |
| <b>Overcapacity</b>           | The capacity to accommodate higher technical specifications than initially required.                                                                                                                                 |
| <b>Passive flexibility</b>    | The ability of a product to facilitate spatial or functional flexibility without undergoing change itself.                                                                                                           |
| <b>Process flexibility</b>    | Flexibility that allows for changes to the design during the development and construction phases.                                                                                                                    |
| <b>Reconfigurability</b>      | The possibility to rearrange parts or components in relation to each other.                                                                                                                                          |
| <b>Remountability</b>         | The possibility to directly reuse a component without or with only minor repairs.                                                                                                                                    |
| <b>Removability</b>           | The capacity to remove a component from a system without negative consequences to the technical functioning of the system.                                                                                           |

|                              |                                                                                                                               |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| <b>Replaceability</b>        | The possibility to replace a component with the same component.                                                               |
| <b>Scalability</b>           | The capacity of the building or building component to change in size or capacity.                                             |
| <b>Service life</b>          | The period of time during which a building remains in use.                                                                    |
| <b>Spatial flexibility</b>   | Flexibility that allows for changes to the spatial configuration and dimensions without the need for structural intervention. |
| <b>Standardisation</b>       | The use of the same component sizes and construction details throughout the building.                                         |
| <b>Technical flexibility</b> | The capacity of a building component to accommodate adaptation.                                                               |
| <b>Technical lifespan</b>    | The period of time during which the building is technically reliable.                                                         |
| <b>Upgradability</b>         | The possibility to improve the performance of a component.                                                                    |
| <b>Use flexibility</b>       | Flexibility that allows for changes to the design during the use phase.                                                       |



# Part I: Research framework

Part I presents the research framework. First, a short introduction with the motivation for the thesis topic is given. This is followed by the problem context, providing the background information and motivation for the research aim. Then the research plan is established, formulating the research aim, research scope, main research questions, and corresponding sub-questions as well as the methodology used to answer them. Finally, a reading guide for the thesis is presented.

## 1 Introduction

Together as a society, we are currently faced with the important task of reducing climate change and environmental strain and creating a more sustainable future. This is an imposing task and a challenge that can be intimidating. Not just for society as a whole but also for the individual parties that need to implement changes in order to make a positive impact. The parties within the building industry also have their part to play in the transition towards a more sustainable future.

One way to address this daunting challenge is to come up with practical solutions or alternatives that can contribute to the sustainability of building projects and can this way help improve the sustainability of the total building industry incrementally. In the development of such practical solutions, it should be taken into consideration that new sustainable products or methods are more likely to be swiftly adopted in everyday practice if they also provide additional advantages to stakeholders of building projects, aside from sustainability.

This thesis aims to contribute to the gradual improvement of the sustainability of the building industry by exploring the implementation of flexible design for floor systems as a practical solution that can contribute to a circular building industry.

## 2 Problem context

In this chapter, the problem context of the research project is described. The focus is on the theory behind circularity and flexibility and how flexible design can contribute to the circularity of buildings and building components. Also, Van Wijnen's approach and ambitions with regard to circular building design and construction are discussed.

### 2.1 Circular economy

The currently prevailing linear economic model relies on large quantities of readily available raw materials and energy and causes environmental strain and depletion of natural resources (Cheshire, 2016; Luscuere, 2018; Reichel et al., 2016; Verberne, 2016). The natural resources are extracted, manufactured, consumed, and finally downcycled or turned into waste (Geldermans et al., 2016; Luscuere, 2018; Merrild et al., 2016; van Leeuwen et al., 2018). As a result, the value of the material, generated during extraction and production, is lost (Merrild et al., 2016).

The building industry is a heavy user of raw materials. Globally, the building industry is responsible for up to 40% of the materials used (Merrild et al., 2016). In the Netherlands, the building industry is estimated to be responsible for 50% of the resource consumption (Rijksoverheid, 2016). In addition, the building industry also produces large quantities of construction and demolition waste. About 35% and 40% of all the waste in the world and the Netherlands respectively, is related to construction and demolition waste (Merrild et al., 2016; Rijksoverheid, 2016). This large scale consumption of resources puts a heavy strain on the environment (Ollongren, 2019; Rijksoverheid, 2018).

A transition to a circular economic model could provide a solution to the challenges with regards to resource depletion and environmental strain (Geldermans et al., 2016; Osobajo et al., 2020; van Stijn & Gruis, 2019). In a circular economy, the value of resources, materials, and products are preserved by keeping them available in the economy for as long as possible (Cheshire, 2016; European Commission, 2015; Reichel et al., 2016). This way, fewer resources are needed, and the consumption of raw materials and energy and the production of waste is reduced (Reichel et al., 2016; van Leeuwen et al., 2018).

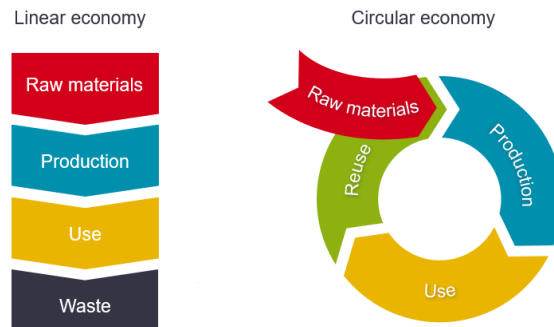


Figure 1: From a linear to a circular economy, adapted from 'Werking circulaire economie' (Rijksoverheid, n.d.)

Regenerative and restorative use of resources form the basis of a circular economy (Ellen MacArthur Foundation, 2013; Geldermans & Jacobson, 2015). In principle, there is no waste in a circular economy. Products and components are designed to cycle back into use at the end of their life, as illustrated by figure 2 from the Ellen MacArthur Foundation (2013). Figure 2 also shows that a distinction can be made between biological and technical cycles (Ellen MacArthur Foundation, 2013; Merrild et al., 2016). The biological cycles represent materials, such as wood, that can be returned to the environment after use without polluting nature (Cheshire, 2016; Merrild et al., 2016). The technical cycles embody materials, such as concrete and steel, that are unsuitable to be returned to nature and should be designed to cycle as long as possible (Cheshire, 2016; Ellen MacArthur Foundation, 2013).

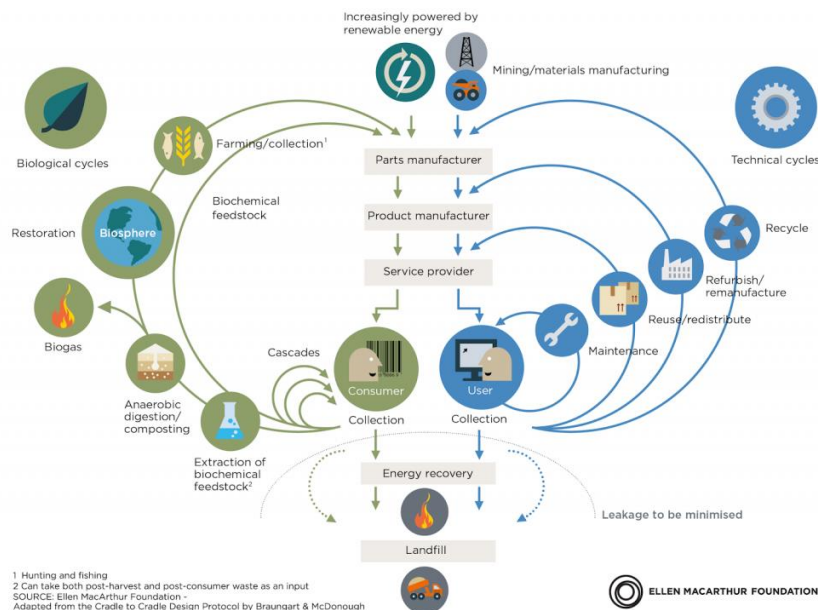


Figure 2: Circular Economy system diagram (Ellen MacArthur Foundation, 2013)

Materials should preferably cycle in the tightest inner cycle possible in order to preserve embedded materials, labour, and energy and reduce the need for additional raw materials due to the inefficiencies along the supply chain associated with the outward cycles (Ellen MacArthur Foundation, 2013, 2015; Merrild et al., 2016). In a circular system, the materials should also cycle as long as possible. This could be achieved by maximizing both the time spent in each cycle, by extending the service life of the product, and the number of consecutive cycles, by facilitating reuse (Ellen MacArthur Foundation, 2013, 2015; Merrild et al., 2016). When materials cycle longer, the need for new natural resources is prevented (Lacy et al., 2014).



Figure 3: Tight inner cycles and long cycling in a circular system (Ellen MacArthur Foundation, 2015)

The importance of a shift towards a circular economy is widely acknowledged. The European Union has set the goal to achieve a circular economy by 2050 and has published a strategy to support this transition (European Commission, 2015; European Union, 2013). The Dutch government has endorsed this goal. In 2016, the national program ‘Nederland circulair in 2050’ was published in which the Dutch government formulated the ambition for a fully circular economy before 2050 (Rijksoverheid, 2016). This program specifically mentions the building industry as one of the five main priorities in the transition to a circular economy. Since then, circularity was given a central role in De Bouwagenda (Taskforce Bouwagenda, 2017) and a transition agenda has been published to guide the building industry through the transition (Rijksoverheid, 2018).

## 2.2 Service life

The service life of a building is the time during which it remains in use (van den Dobbelsteen, 2004). It depends on its technical, economical, and functional lifespan and is determined by the shortest of the three (Gijsbers, 2011). The technical lifespan indicates the time during which the building is technically reliable (Blok & Teuffel, 2014; Gijsbers, 2011; SenterNovem, 2009). The economical lifespan is the period in which the future revenue is higher than the future costs (SenterNovem, 2009). After this time, the building is no longer profitable. The functional lifespan is the period in which the functional requirements of the users are still met (Gijsbers, 2011; SenterNovem, 2009; van den Dobbelsteen, 2004; van Nunen et al., 2003). In addition, cultural and aesthetical values can also influence the service life of a building (Blok & Teuffel, 2014; SenterNovem, 2009).

A dynamic society, changes in trends and composition of occupants, and new users result in new expectations and requirements for the functionality of a building (Durmisevic, 2006; Landman, 2016; Merrild et al., 2016; Russell & Moffatt, 2001; SenterNovem, 2009). Due to frequently changing user demands, the functional lifespan is usually shorter than the economical and technical lifespan (Blok & van Herwijnen, 2005; Durmisevic, 2006; van Nunen et al., 2003). Therefore, in most cases, the service life of a building is determined by the functional lifespan (Durmisevic, 2006; Post et al., 2006; van den Dobbelsteen, 2004). This means that generally the service life of a building can be extended by prolonging its functional lifespan.

In a circular building industry, materials should cycle as long as possible (Ellen MacArthur Foundation, 2015). This can be achieved by prolonging the service life of the buildings and components in which the materials are incorporated. As the functional lifespan of buildings is often limited by the frequently changing user demands and buildings are often demolished because of their inability to adapt to new requirements, the service life of buildings can be extended if the building is able to respond to changing circumstances and user demands (Blok & van Herwijnen, 2005; Durmisevic, 2006; Geraedts et al., 2014; Gijsbers, 2011; Landman, 2016; Leupen, 2002; Russell & Moffatt, 2001). This can be realised through flexible design of the buildings and their structure, allowing for reconfiguration without the need for major interventions (Blok & van Herwijnen, 2005; Gijsbers, 2011; Landman, 2016; Merrild et al., 2016; Schmidt et al., 2011; van den Dobbelsteen, 2004).

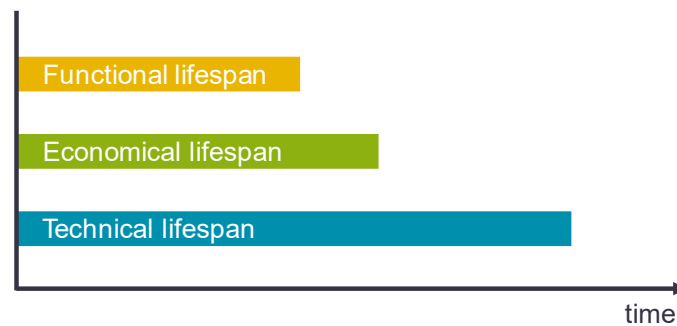


Figure 4: Schematisation of the functional, economical, and technical lifespan of a building

## 2.3 Flexibility

Flexibility indicates the capacity of a building to adapt to changing circumstances and user requirements (Geraedts, 1996; Gijsbers, 2011; Schmidt et al., 2011). In order to realise flexibility without the need for intrusive structural intervention, building components need to be adaptable. Adaptability is a technical property that indicates if a building component can take on physical and lasting changes without consequences to other building components (Gijsbers, 2011; Gijsbers & Lichtenberg, 2012; Platform CB'23, 2020). Different forms of adaptability or indicators of flexibility include accessibility, scalability, reconfigurability, demountability, and upgradability (Durmisevic, 2006; Gijsbers, 2011; Russell & Moffatt, 2001; Schmidt et al., 2014). In literature, there is little agreement on the difference between the concepts of flexibility and adaptability, the terms are often used interchangeably (Gosling et al., 2008).

### 2.3.1 Flexibility as a circular design strategy

To realise a circular building sector, the current approach to designing buildings and their components has to be re-evaluated. The political and societal push towards circularity requires a high speed of change. This high speed of change results in a difficult to predict and turbulent context for companies to operate within (Ansoff & McDonnell, 1990; Moussetis, 2011). The changing context calls for a novel and creative strategy that matches the level of external turbulence (Ansoff & McDonnell, 1990; Porter, 1996). A design strategy is a long-term vision on how to use design at a product level to achieve an overarching goal (Best, 2006; Navarro Aguiar, 2016). For the building industry, this means coming up with a vision on how to use design at a building or building component level to achieve circularity.

Flexibility and adaptability are identified in literature as part of the key design strategies to achieve a circular building sector (K. T. Adams et al., 2017; Eberhardt et al., 2020; European Commission, 2020). Longer cycling of building materials and components can be accomplished by extending the service life of the building in its intended use and more consecutive cycles can be achieved by enabling reuse for another purpose (European Commission, 2020; Naber, 2012; Schmidt et al., 2011). In both cases, flexible design is of importance to accommodate changes in circumstances, demands, and use and ensure the continued usage of the building and its components (Durmisevic, 2006; European Commission, 2020; Geraedts et al., 2014).

Flexible design accommodates changes and service life extension through facilitation of for example reconfiguration, upgradability, and maintenance. Reconfiguration offers the possibility to change the spatial layout in accordance with changing needs and uses (Durmisevic, 2006). Upgradability allows for easier and cheaper upgrading of outdated technologies and adoption of new technological innovations (Durmisevic, 2006; Gijsbers, 2011; Merrild et al., 2016; Russell & Moffatt, 2001). Through flexible design aspects like accessibility and exchangeability, building components can easily be maintained, repaired or replaced without hindrance from other building components (Durmisevic, 2006; Eberhardt et al., 2020; European Commission, 2020; Merrild et al., 2016).

### 2.3.2 Flexibility for stakeholders

Besides the benefits with regards to circularity, flexible design can also be advantageous to the owners and users of buildings (Eberhardt et al., 2020). The residents of a building are dynamic and change continuously in size, composition, occupation, and hobbies during their lifetime (Gijsbers, 2011). Flexible

design can facilitate people to (continue to) live in a building through every stage of life by offering the possibility to adapt their surroundings to their evolving needs (Gijsbers, 2011; Leupen, 2002).

For building owners, it is beneficial to be able to adapt their building stock to the changing user requirements against reduced reinvestment costs (Durmisevic, 2006; Schmidt et al., 2011). About half of the investments in building construction are spent on adaptation and maintenance (Durmisevic, 2006). Through flexible design, vacancy, early depreciation, and high transformation costs can be prevented (Durmisevic, 2006; Geraedts, 1996; Merrild et al., 2016). In addition, flexibility facilitates maintenance and reparations through accessibility and exchangeability, reducing the operation and maintenance costs for the owner (Durmisevic, 2006; Eberhardt et al., 2020; Gijsbers, 2011; Merrild et al., 2016).

Flexible design can, however, require a higher initial investment (de Vos-Effting et al., 2017; Gijsbers, 2011). As the future is uncertain, it is unknown in advance if the flexibility measures will be used and thus if the increased initial investment will be worth it (de Vos-Effting et al., 2017; Geraedts, 1996; Gijsbers, 2011). This financial uncertainty can form an obstacle to the realisation of flexible building design. Especially considering that the initial burdens are usually for a different party than the generated benefits during the lifetime of the building (K. T. Adams et al., 2017; Geraedts, 1996; Russell & Moffatt, 2001). On the other hand, incorporating flexibility in the building design can reduce the financial risk of premature writing off of the building structure (Gijsbers, 2011; Post et al., 2006; Veldhoen et al., 1995). Overall, the long-term operation, maintenance, and adaptation costs over the service life of a building outweigh the initial investment costs (Schmidt et al., 2011). As a result, flexible building design may be more expensive at completion, but not when taking into account the total cost of ownership (van Leeuwen et al., 2018).

## 2.4 Theory of layers

Each component of a building has its own separate lifespan and its own replacement or maintenance rate (Geldermans & Jacobson, 2015; Rijksoverheid, 2018; van den Dobbelsteen, 2004; van Leeuwen et al., 2018). The dimension of time in building design was first introduced by Habraken (Teerds et al., 2011). Habraken (1961) differentiated between the support and the infill of a building. The support forms the basis of the building and is of a more permanent nature, the infill is changeable and is determined by personal and societal context (Habraken, 1961; Teerds et al., 2011). Duffy (1990) also asserted the importance of discerning building parts in terms of time and distinguished 4 different layers: shell, services, scenery and set. Brand (1994) expanded on Duffy's layers. Based on their service life, he identified site, structure, skin, service, space plan, and stuff as the different shearing layers of a building (Brand, 1994). According to Brand, maintenance, replacement, or refurbishment of one layer should have no obstruction from other layers with a lengthier service life.

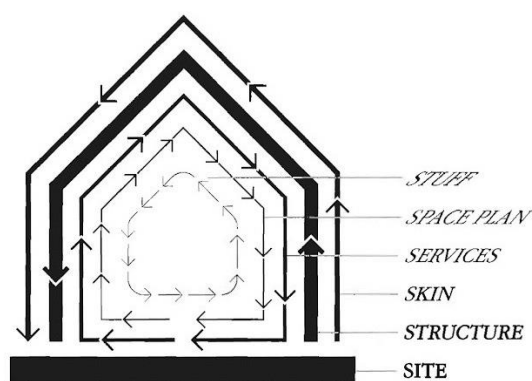


Figure 5: Shearing layers of change (Brand, 1994)

Nevertheless, components with a shorter service life are often integrated into a fixed assembly with the load-bearing structure, which has a much longer lifespan (Brand, 1994; Durmisevic, 2006; Durmisevic & Brouwer, 2002). Due to this integration, replacement or alteration of one element means serious damage to or demolition of the other element (Durmisevic, 2006; Durmisevic & Brouwer, 2002; Gijsbers, 2011). By technically and physically decoupling building components from different layers it becomes possible to adapt or replace one component without affecting the performance of the other, increasing the



flexibility of the building (Blok & van Herwijnen, 2005; Brand, 1994; Gijsbers, 2011; Landman, 2016; Leupen, 2002; Russell & Moffatt, 2001; Schmidt et al., 2011).

Durmisevic (2006) identified that fixed integration between load-bearing and non-load-bearing parts of the building, inflexible installations systems that cannot easily adapt to different spatial typologies, lack of accessibility to the old installations, and lack of space for new installations are some of the key obstacles for the successful transformation of buildings. Lichtenberg (2005) also emphasized the interconnection between the building services and structural elements as an important obstruction to adaptability. In Dutch housing, building services are often cast into the floors and walls, creating one fixed element (Durmisevic, 2006; Landman, 2016). However, the service lives of the structural and services layers are vastly different, 30-300 years and 7-15 years respectively (Brand, 1994). As a result, the integration of these two layers forms a significant obstacle to the flexibility of the building component.

## 2.5 Van Wijnen factory

In the fall of 2020, Van Wijnen announced its investment in a new factory in Heerenveen (Van Wijnen Groep, 2020). This factory will be producing prefabricated modular 'building kits' for Van Wijnen's housing concepts, which afterwards only need to be assembled on the construction site (Van Wijnen Groep, 2020; van Zijl & Hutten, 2020; Vastgoed Business School, 2020). The houses can be built at a fast rate and are demountable so that the modular components can be reused (Husson, 2020; Transport Online, 2020; Van Wijnen Groep, n.d., 2020; Vastgoed Business School, 2020). This way, Van Wijnen aims to address the housing shortage through an affordable and circular solution (Van Wijnen Groep, 2020; Vastgoed Business School, 2020).

In terms of circularity, the current focus of Van Wijnen is on demountability. Flexibility and demountability are closely related circular design strategies and share several design factors. For example, detachability is not only important for demountability but also plays an important role in flexibility indicators such as reconfigurability, replaceability, and upgradability. In addition to demountability, flexibility can also provide added value both during and after a use cycle of a building. In use, the building can be adapted to changing user requirements, extending the service life of the building. After a use phase, flexibility provides the possibility to adapt or upgrade building components to new standards and requirements before reusing them.

## 3 Research plan

The research plan describes the approach for the research project. The research aim, scope, and main research question were formulated to shape the focus of the research. The sub-questions help navigate the research process. Per sub-question, the methodology used is described.

### 3.1 Research aim

The transition towards a fully circular building industry starts with the implementation of circularity measures within the current production processes of the existing building industry. The integration of building services within the load-bearing structure forms an obstacle to the flexibility and demountability of buildings and building components and thereby to their circularity (Durmisevic, 2006; Lichtenberg, 2005). Therefore, the integration of these two layers is the focal point of this research. The housing concept by Van Wijnen intended for factory production is taken as a case study. In residential buildings, the building services are primarily found in the floors for horizontal distribution (Cox et al., 2006; Sarja, 2000). The focus is on floor systems for terraced houses, as these floors are less optimised and less complex than in apartment buildings and therefore have more room for improvement. Ultimately, this leads to the research aim for this thesis:

*To determine the effectiveness of flexibility measures regarding the integration of the building services and load-bearing functions in improving the circularity of prefabricated floor systems in modular residential buildings.*



### 3.2 Scope

To keep the research focused and manageable, the scope of this thesis consists of the following aspects:

- The research regards flexibility as a means to contribute to circularity.
- The research covers floors in terraced houses located in the Netherlands.
- The research concerns prefabricated floors produced in a factory production process.
- The research focuses on the building services and structural functions of floor systems.

### 3.3 Research questions and methods

The research objective leads to the following main question:

*To what extent can flexibility measures improve the circularity of prefabricated floor systems in residential buildings?*

In order to adequately answer the main question, several sub-questions were formulated, and the method used to answer these questions is described. The sub-questions can be divided into those that form the theoretical framework for the thesis and those that are related to the case study.

#### Theoretical framework

The theoretical framework provides the academic underpinning for the analysis and interpretation of the case study (Crowe et al., 2011; Fellows & Liu, 2015). To form the theoretical framework, an exploratory study was done on flexible design, flexible floor systems, and the assessment of circularity and flexibility in order to identify key concepts, variables, and theories (Fellows & Liu, 2015). The theoretical framework was compiled based on the first four sub-questions.

1. *How can flexible design be integrated in floor systems?*
  - a. *What design factors influence the flexibility of (building) products?*
  - b. *What are the opportunities and challenges for the implementation of flexibility measures in floor systems?*

Sub-question 1a was answered through a literature study on design factors that influence the flexibility of products and indicators of flexible design. This literature study was not limited to flexibility in the building sector but also included literature on flexibility of other types of products. Sub-question 1b was answered through semi-structured interviews with people involved in different parts of the decision and design process of building projects in order to gather information from different perspectives on possible opportunities and challenges for flexible design.

2. *To what extent are flexible floor systems for residential buildings already available on the market?*
  - a. *What solutions for flexible floor systems already exist?*
  - b. *How do the existing solutions for flexible floor systems include flexibility measures in their design?*
  - c. *What are the advantages and drawbacks of the existing solutions for flexible floor systems?*

To gain insight into the current state of flexible floor systems, a literature study was done into the previously developed designs and solutions available on both the Dutch and international market. To answer sub-question 2b, the flexibility measures included in the floor systems were investigated through the literature found on the floors and through comparison with the flexible design factors found in sub-question 1a. The advantages and drawbacks of the existing designs were also assessed through the literature found on the floors, in combination with a comparison with the flexibility indicators and design factors found in sub-question 1a and the challenges and possibilities identified through sub-question 1b.

3. *How are the costs of a floor system influenced by the design?*
  - a. *What are the costs for the traditionally used floor systems and the existing flexible floor designs?*
  - b. *What design factors influence the costs of a floor system?*

From the interviews for sub-question 1b, it became apparent that the costs are an important factor in the likelihood of a new flexible floor system to be adopted in practice. Information on the costs of traditionally used floor systems and the existing flexible floor systems was gathered from the literature found for sub-question 2. Based on the available cost information, a qualitative comparison was done of the designs

of the floor systems and their cost range to determine what design factors influence the costs of a floor system.

4. *How can the effect of flexibility measures on the circularity of floor systems be assessed?*
  - a. *What methods exist to assess the circularity of building components?*
  - b. *What methods exist to assess the flexibility of building components?*
  - c. *Which assessment method is most relevant to assess the effect of flexibility measures on the circularity of a building component?*

To show the effect of flexibility measures on the circularity of floor systems, the degree of flexibility and circularity of the building component had to be made quantifiable and comparable. Through a literature study, the existing assessment methods for flexibility and circularity of building components were identified. The methods were evaluated and compared to figure out which of the methods were most relevant for the study at hand. For the flexibility assessment, no applicable assessment method was found and therefore a new flexibility assessment method was developed.

### **Case study**

The case study provides a delimited area of study to place the theoretical framework in a practical context (Crowe et al., 2011; Rowley, 2002; Scholz & Tietje, 2002; Stokes, 2017). It concerns an instrumental case study, used to gain a more in-depth understanding of the practical implications of the theoretical insights regarding flexible floor systems and circularity (Crowe et al., 2011). Sub-questions 5 to 10 form a guide through the analysis, investigation, and interpretation of the case study.

5. *What is the current design of the floor system?*
  - a. *What are the dimensions of the current floor design?*
  - b. *What are the structural and technical properties of the current floor design?*
  - c. *What building services are integrated in the current floor design?*

This sub-question acted as a guide to get familiar with the current design of the floor system. The dimensions of the floor system, the building services integrated into the floor and the structural and technical properties of the design were identified through a study of the existing drawings and calculations. Information on the design of the connection details was gathered through the questioning of a structural engineer familiar with the design. Due to the confidentiality of the design, not all properties of the floor system are included in this report.

6. *How can the flexibility and circularity of the current design of the floor system be improved?*
  - a. *How circular is the current design of the floor system?*
  - b. *How flexible is the current design of the floor system?*
  - c. *Which aspects of the current floor design can be redesigned to improve the flexibility and circularity of the floor system effectively?*

To answer sub-questions 6a and 6b, the assessment methods selected and developed at sub-question 4 were applied to the current design of the floor system, the traditional floor systems, and the existing flexible floor designs found under sub-question 2. The results from this assessment were evaluated to see where improvement is possible in the circularity and flexibility of the current design.

7. *What are the requirements for the design of the floor system?*
  - a. *What building code requirements are relevant for the design of the floor system?*
  - b. *What are the stakeholder requirements for the design of the floor system?*

This sub-question resulted in an overview of the relevant requirements for the design of the floor system. For sub-question 7a, the relevant structural and building physics requirement were determined through a study of the Eurocodes and the Dutch Building Decree. To answer sub-question 7b, a rudimentary stakeholder analysis was done to identify the additional requirements for the key stakeholders, such as the investor, owners, and users.

8. *Does the floor system meet the requirements when flexibility measures are included?*
  - a. *Does the floor system meet the building code requirements when flexibility measures are included?*

*b. Does the floor system meet the stakeholder requirements when flexibility measures are included?*

Based on the evaluation in sub-question 6c, points of improvement for the circularity and flexibility of the current floor design were identified. These points of improvement were taken as input for the development of several design concepts. These design concepts were developed, verified, adapted, and sometimes discarded based on the building code and stakeholder requirements from sub-question 7. Through an iterative design process, the requirements were met as much as possible.

*9. To what extent does the inclusion of flexibility measures in the floor design improve the circularity of the floor system?*

*a. How flexible is the floor design when flexibility measures are included?*

*b. How circular is the floor design when flexibility measures are included?*

*c. Is the circularity of the floor improved by the inclusion of flexibility measures in the design?*

Sub-questions 9a and 9b were answered by applying the assessment methods selected and developed at sub-question 4 to the new design concepts for the floor system. The results were compared to the results found in sub-questions 7a and 7b and the differences were evaluated to show the effect of the flexibility measures on the circularity of the floor systems.

*10. To what extent does the inclusion of flexibility measures in the floor design affect the circularity of the building as a whole?*

*a. How does the inclusion of flexibility measures in the floor design affect the rest of the building?*

*b. How is the circularity of the rest of the building affected by the inclusion of flexibility measures in the floor design?*

Changes to the design of the floor systems could have an effect on the rest of the building structure. How the changes in the floor design could affect the rest of the building was outlined for sub-question 10a, by identifying changes in the floor design and their effect on the rest of the structure. For sub-question 10b, the effect of these changes on the circularity of the rest of the building was evaluated. In both cases, the assessment was done qualitatively to avoid time-consuming calculations using uncertain values.

## 4 Reading guide

Figure 6 gives an overview of the thesis contents and which research questions are addressed in what chapters.

|                                         |                                        |    |    |
|-----------------------------------------|----------------------------------------|----|----|
| <b>Part I</b><br>Research framework     | Chapter 1<br>Introduction              |    |    |
|                                         | Chapter 2<br>Problem context           |    |    |
|                                         | Chapter 3<br>Research plan             |    |    |
|                                         | Chapter 4<br>Reading guide             |    |    |
| <b>Part II</b><br>Theoretical framework | Chapter 5<br>Flexible design           | Q1 |    |
|                                         | Chapter 6<br>Existing solutions        | Q2 | Q3 |
|                                         | Chapter 7<br>Assessment methods        | Q4 |    |
| <b>Part III</b><br>Case study           | Chapter 8<br>Current design            | Q5 | Q6 |
|                                         | Chapter 9<br>Development of new design | Q7 | Q8 |

|                              |                                        |    |     |
|------------------------------|----------------------------------------|----|-----|
|                              | Chapter 10<br>Evaluation of new design | Q9 | Q10 |
| <b>Part IV</b><br>Conclusion | Chapter 11<br>Discussion               |    |     |
|                              | Chapter 12<br>Conclusions              |    |     |
|                              | Chapter 13<br>Recommendations          |    |     |

Figure 6: Reading guide

# Part II: Theoretical framework

Part II deals with the theoretical framework of the research. It provides the academic and theoretical foundation for the analysis and interpretation of the case study. Based on the first four sub-questions, ways to incorporate flexibility in design, existing flexible floor systems, cost influencing factors, and assessment methods for flexibility and circularity of building components are discussed.

## 5 Flexible design

Sub-question 1 “*How can flexible design be integrated in floor systems?*” is addressed in two parts. The first part concerns a literature study on the factors that influence the flexibility of design. In the second part, the opportunities and challenges associated with flexible design of floor systems are discussed in interviews with people experienced in different relevant subject areas.

### 5.1 Flexible design factors

Research question 1a “*What design factors influence the flexibility of (building)products?*” is answered through a literature study on the indicators of flexible design and design factors that influence the flexibility of products. This literature study is not limited to flexibility in the building sector but also includes literature on flexible design in other fields. The approach for the literature study is outlined in Appendix A. As a result of the literature study, the different categories of flexibility are outlined and an overview is given of the design factors that were identified to be of importance for flexible design.

#### 5.1.1 Categories of flexibility

In the literature, distinctions are made between different categories or types of flexibility. For example, Gijsbers (2011) differentiates between process flexibility and use flexibility. Process flexibility indicates the possibility for the first user to adapt the design to their personal wishes during the development and construction phase and use flexibility entails the capacity of a building to be adapted during the use phase with only limited structural intervention (Gijsbers, 2011). The focus of this research is on flexibility during and between use cycles. Therefore, categories such as process flexibility are not taken into consideration. Because this research is concerned with the flexibility of building components, flexibility related to changes in the interior without changes to the fabric of the building are also not included (Heidrich et al., 2017).

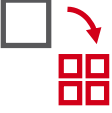
For flexibility during and between use cycles, two main categories of flexibility can be identified. The first category is spatial flexibility (Geldermans et al., 2019a; Gijsbers, 2011; Hermans et al., 2014; Sadafi et al., 2014). Spatial flexibility allows for changes to the spatial configurations and dimensions without the need for intrusive structural intervention (Geldermans et al., 2019a; Gijsbers, 2011). The second category is functional flexibility, which enables the change of use of a space without changing its spatial structure (Gijsbers, 2011; Keymer, 2000). This category includes, for example, the possibility to upgrade the performance of building components or to modify or add facilities (Keymer, 2000).

Both categories of flexibility require technical flexibility (Gijsbers, 2011; Hermans et al., 2014). Technical flexibility indicates the capacity of a building component to accommodate adaptation due to changing requirements or conditions (Gijsbers, 2011; Hermans et al., 2014; Keymer, 2000; Sadafi et al., 2014). However, technical flexibility is not a category on its own, it serves to realise spatial or functional flexibility (Gijsbers, 2011; Hermans et al., 2014). Technical flexibility can be either active or passive (Gijsbers, 2011; Zwakhals et al., 2012). A building component is passively flexible when it facilitates adaptation without undergoing change itself (Gijsbers, 2011). In the case of active flexibility, the component itself is adapted to enable spatial or functional flexibility (Gijsbers, 2011; Zwakhals et al., 2012).

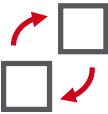
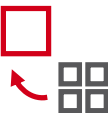
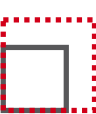
#### 5.1.2 Design indicators of flexibility

The full list of all factors mentioned in the literature to be of importance for flexible design can be found in Appendix A.6. Table 1 provides a condensed version of this overview. It only includes design factors that were mentioned by two or more sources. In addition, the design factors fire safety and insulation are merged with the design factor overcapacity, as both factors mean that overcapacity in these domains allows for a change of function to a function that has stricter requirements.

Table 1: Factors that influence the flexibility of design

| Name                                                                                                               | Also known as                                                                                                                        | Sources                                                                                                                                                                                                                                     | Meaning                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| <b>Accessibility</b><br>          | Accessible, <i>bereikbaarheid</i> , physical access, reachability, <i>toegankelijkheid</i>                                           | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Ross et al., 2016)                                                                                                                | Access to the component that needs to be adapted without hindrance from other components.                        |
| <b>Demountability</b><br>         | Demountable, design for deconstruction, design for disassembly, dismantlable, disassembly, separable, simplify demolition            | (Geldermans et al., 2019a; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Schmidt et al., 2014; Webb et al., 1997; Zwakhals et al., 2012) | The capacity to deconstruct the components from the building and deconstruct components into their constituents. |
| <b>Durability</b><br>             | Durable                                                                                                                              | (Di Sivo & Cellucci, 2013; Sadafi et al., 2014; Zwakhals et al., 2012)                                                                                                                                                                      | The capacity of materials and systems to continue to be useful after an extended period of time and usage.       |
| <b>Independence</b><br>         | Clustering, <i>desintegratie</i> , flexibility, layering of components, no integration, reduced interaction, segregation, separation | (Di Sivo & Cellucci, 2013; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Sadafi et al., 2014; Schmidt et al., 2014)                                                              | The technical separation of elements of different service lives and functions.                                   |
| <b>Integration</b><br>          | Clustering, <i>integratie</i>                                                                                                        | (Gijsbers, 2011; Schmidt et al., 2014)                                                                                                                                                                                                      | The technical coupling of components that will never be adapted separately.                                      |
| <b>Interface simplicity</b><br> | Flexible interfaces, mechanical connections, pluggable connections, simplicity                                                       | (Esper, 2005; Heidrich et al., 2017; Ross et al., 2016; Sadafi et al., 2014)                                                                                                                                                                | The use of uncomplicated mechanical connections between elements.                                                |
| <b>Modularity</b><br>           | Modularization, modular, <i>modulatie</i> , <i>universele moduulmaten</i>                                                            | (Di Sivo & Cellucci, 2013; Esper, 2005; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Webb et al., 1997; Zawidzki, 2016)                                | The consistent use of matching building blocks that can form into a larger component or system.                  |
| <b>Movability</b><br>           | Mobility, movable, <i>verplaatsbaar</i> , <i>verplaatsbaarheid</i>                                                                   | (Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                                                                                                             | The possibility to place a building component at a new location.                                                 |
| <b>Overcapacity</b><br>         | Capacity, <i>overcapaciteit</i> , <i>overgedimensioneerd</i> , redundancy, reserve capacity, surplus                                 | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014)                                                                                                          | The capacity to accommodate higher technical specifications than initially required.                             |



| Name                                                                                                          | Also known as                                                                                                                                                  | Sources                                                                                                                                                                                                                    | Meaning                                                                                                                    |
|---------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| <b>Reconfigurability</b><br> | Adjustability, <i>indelingsflexibiliteit</i> , rearrangeable, <i>reconfigureerbaar</i> , transformable, <i>veranderbaarheid</i> , versatile                    | (Esper, 2005; Geraedts, 2016; Gijsbers, 2011; Hermans et al., 2014; Manewa et al., 2016; Schmidt et al., 2014; Zawidzki, 2016)                                                                                             | The possibility to rearrange parts or components in relation to each other.                                                |
| <b>Remountability</b><br>    | <i>Hoogwaardig hergebruik</i> , reassembly, reusable, reuse                                                                                                    | (Geldermans et al., 2019a; Gijsbers, 2011; Manewa et al., 2016; Sadafi et al., 2014)                                                                                                                                       | The possibility to directly reuse a component without or with only minor repairs.                                          |
| <b>Removability</b><br>      | <i>Afstotingsflexibiliteit</i> , disposability, ejectable, rejectability, <i>verwijderbaarheid</i>                                                             | (Geraedts, 2016; Gijsbers, 2011; Hermans et al., 2014; Manewa et al., 2016)                                                                                                                                                | The capacity to remove a component from a system without negative consequences to the technical functioning of the system. |
| <b>Replaceability</b><br>    | Exchangeable, refitable, replaceable, <i>vervangbaar</i>                                                                                                       | (Geraedts, 2016; Gijsbers, 2011; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                                                                                                                         | The possibility to replace a component with the same component.                                                            |
| <b>Scalability</b><br>     | Elastic, elasticity, expendable, extendable, <i>inkrimpbaar</i> , scalable, <i>uitbreidbaar</i> , <i>uitbreidingflexibiliteit</i> , <i>volumeflexibiliteit</i> | (Brunoe et al., 2019; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Landman, 2016; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                                        | The capacity of the building or building component to change in size or capacity.                                          |
| <b>Standardisation</b><br> | Compatibility, interchangeable, regularity, universal                                                                                                          | (Di Sivo & Cellucci, 2013; Esper, 2005; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Webb et al., 1997; Zwakhals et al., 2012)                        | The use of the same component sizes and construction details throughout the building.                                      |
| <b>Upgradability</b><br>   | <i>Kwaliteit</i> , <i>opwaardeerbaarheid</i> , <i>opwaarderingsflexibiliteit</i> , refitable                                                                   | (Esper, 2005; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Schmidt et al., 2014)(Di Sivo & Cellucci, 2013; Esper, 2005; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Schmidt et al., 2014) | The possibility to improve the performance of a component.                                                                 |

Many of the factors in Table 1 are related to each other. For example, movability is required for reconfigurability and for a component to be demountable it should be accessible. Figure 7 paints a picture of the relations between the different design factors, with at the top the different indicators of flexible design and towards the bottom the technical characteristics that make them feasible.

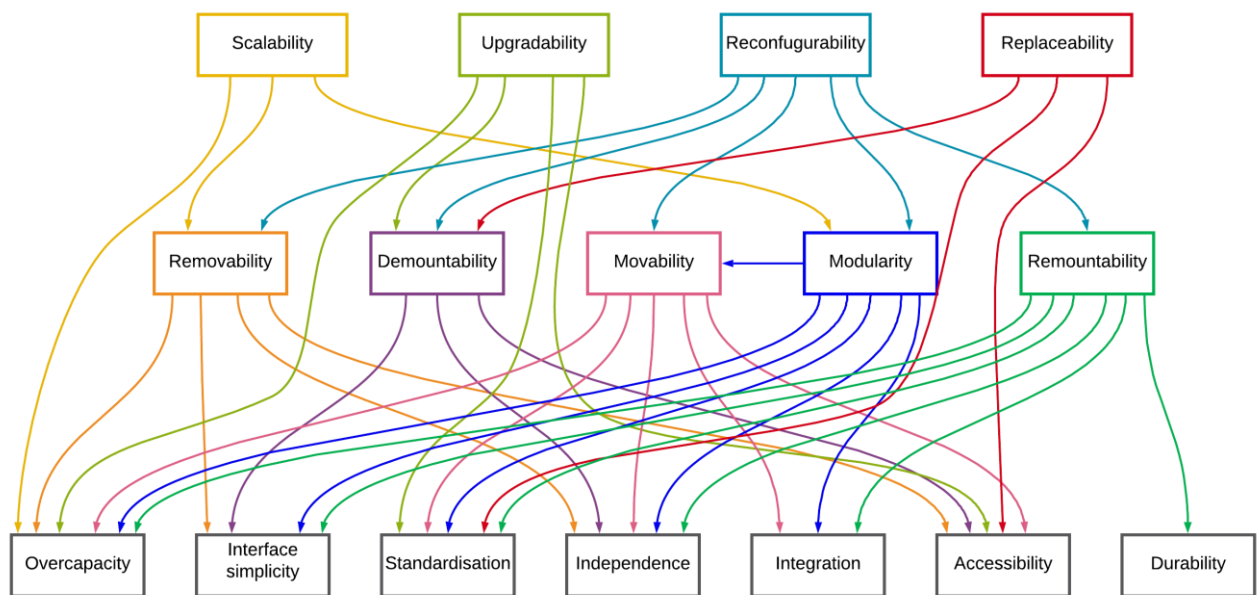


Figure 7: Relations between design factors

### 5.1.3 Conclusions

During and between the use cycles of a building, spatial and functional flexibility can be distinguished as the two main categories of flexibility. Both categories require technical flexibility of the building components, allowing for the desired adaptations without the need for major interventions. There are different ways technical flexibility can be achieved. Reconfigurability, replaceability, scalability, and upgradability are all indicators of flexible design that can be achieved through demountability, modularity, movability, remountability, and removability. Finally, the technical characteristics of flexible design, accessibility, durability, independence, integration, interface simplicity, overcapacity, and standardisation, should be incorporated in the design process to realise flexible design in practice and can thus be identified as the design factors that influence the flexibility of building components. Figure 8 gives an overview of the categories and design factors of flexible design.

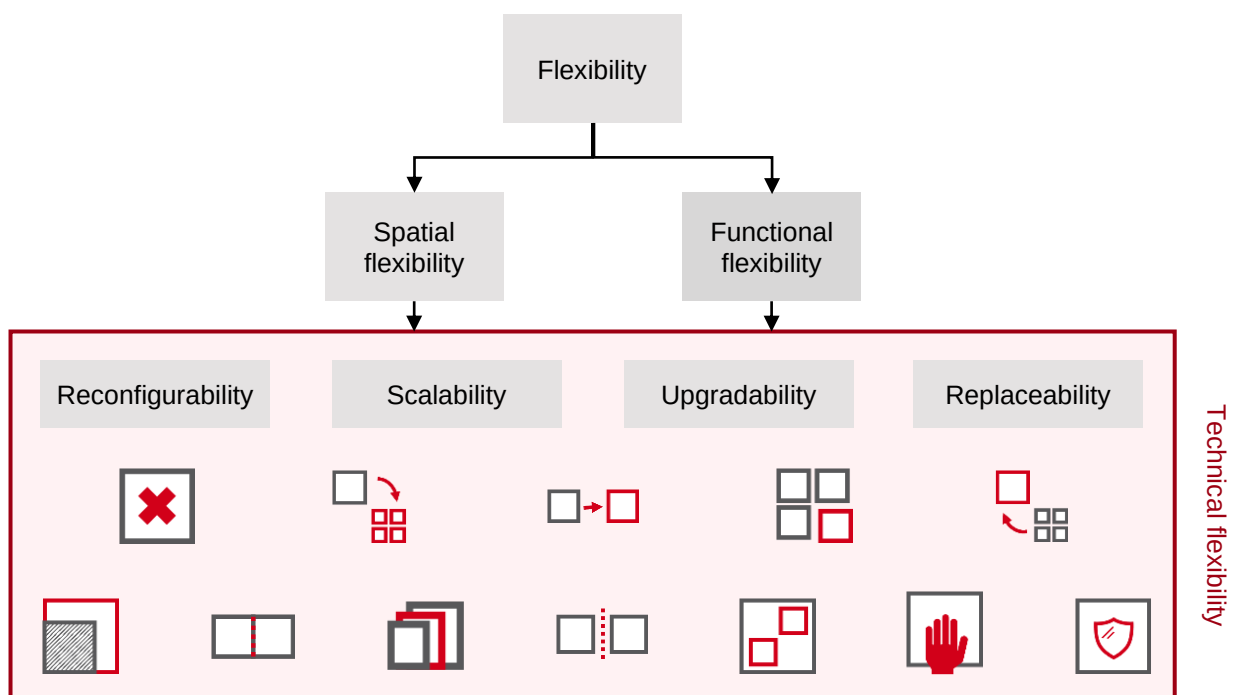


Figure 8: Overview of flexible design categories and factors

## 5.2 Opportunities and challenges of flexible floor design

Sub-question 1b “What are the opportunities and challenges for the implementation of flexibility measures in floor systems?” is answered through semi-structured interviews with people involved in different parts of the decision and design process. First, the interview approach is discussed, after which the interviews are evaluated and the results are presented.

### 5.2.1 Approach

In order to gather information from different perspectives on the possible opportunities and challenges for flexible floor design that might not become apparent from the existing literature, interviews were held with people involved in and experienced with different areas relevant to floor design. The interviews provide in-depth information on the participants' experiences and viewpoints on the current state of affairs and possible future developments (Turner, 2010). The interviews were done as semi-structured interviews, also known as qualitative interviews (W. C. Adams, 2015). Semi-structured interviews employ a combination of open and closed questions and allow for follow up of interesting leads or delving into unforeseen topics outside of the predefined questions (W. C. Adams, 2015; Wilson, 2014).

#### 5.2.1.1 Interview set-up

The goal of the interviews is to explore the possibility of implementing flexibility measures in floor design as a means to improve its circularity, from the perspective of the interviewee. The interviews were held based on the interview guides that can be found in Appendix B.1. This interview guide includes a basic script, questions and possible prompts to encourage follow-up (Wilson, 2014). The interviews were done via videocalls and took up to an hour each. The audio was recorded so that the interviewer could focus on conducting the interview. The informed consent form and the corresponding information sheet can be found in Appendices B.2 and B.3. The interviews were held with 11 people from two different groups. The group of designers includes people involved in and experienced with different parts and different stages of the design process. This group includes four domains: building services, product development, structural design, and architecture. The group of patrons involves people from parties that can induce the adoption of flexible design measures through policy, investments, or otherwise. Table 2 gives an overview of the interviewees and their backgrounds. Because of confidentiality, the identity and personal data of the interviewees are anonymised.

Table 2: Interviewees and their disciplines

| Designers                                                                                                                                                                                                                                                                                                           |                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| <i>Review of the current state of affairs and developments regarding flexibility in their field of expertise, discussion on floor design and related developments in their field, and exploration of the opportunities and challenges for the implementation of flexibility measures within the design process.</i> |                                                                                     |
| Architecture                                                                                                                                                                                                                                                                                                        |                                                                                     |
| P8                                                                                                                                                                                                                                                                                                                  | Architect at a small Dutch architecture firm                                        |
| Building services                                                                                                                                                                                                                                                                                                   |                                                                                     |
| P6                                                                                                                                                                                                                                                                                                                  | Consultant at a small Dutch building services and building physics consultancy firm |
| P7                                                                                                                                                                                                                                                                                                                  | Consultant at a medium-large Dutch building services company                        |
| Product development                                                                                                                                                                                                                                                                                                 |                                                                                     |
| P3                                                                                                                                                                                                                                                                                                                  | Structural engineer and product developer at a small Dutch engineering firm         |
| Structural design                                                                                                                                                                                                                                                                                                   |                                                                                     |
| P1                                                                                                                                                                                                                                                                                                                  | Structural engineer at a large Dutch construction firm                              |
| P5                                                                                                                                                                                                                                                                                                                  | Structural engineer at a medium-large Dutch engineering firm                        |
| Patrons                                                                                                                                                                                                                                                                                                             |                                                                                     |

|                                                                                                                                                                                                      |                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| <i>Review of the current position of flexible structures within their field and exploration of the incentives required for adoption of flexible design in policies and/or investment strategies.</i> |                                                              |
| P2                                                                                                                                                                                                   | Project developer at a large Dutch construction firm         |
| P4                                                                                                                                                                                                   | Client and market manager at a large Dutch construction firm |
| P9 & P10                                                                                                                                                                                             | Project developer at a large Dutch housing corporation       |
| P11                                                                                                                                                                                                  | Policy adviser at the municipality of a large Dutch city     |

#### 5.2.1.2 Processing of interviews

The interviews were processed by means of a thematic analysis. Through thematic analysis, recurring themes are identified in the data by reading and re-reading the information and coding important and relevant extracts (Braun & Clarke, 2006). The steps taken in this analysis are outlined in Table 3. The transcribed and coded interviews can be found in Appendix B.4.

Table 3: Phases of thematic analysis, adapted from 'Using thematic analysis in psychology' (Braun & Clarke, 2006)

|                               |                                                                                                                                                                                                                                              |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Familiarization with data  | <ul style="list-style-type: none"> <li>Transcribing data</li> <li>Reading and re-reading data</li> <li>Noting down initial ideas</li> </ul>                                                                                                  |
| 2. Generation initial codes   | <ul style="list-style-type: none"> <li>Coding interesting extracts across the data set</li> </ul>                                                                                                                                            |
| 3. Search for themes          | <ul style="list-style-type: none"> <li>Collating codes into potential themes</li> </ul>                                                                                                                                                      |
| 4. Review of themes           | <ul style="list-style-type: none"> <li>Checking if the themes work with the coded extracts</li> <li>Checking the validity of the individual themes in relation to the data set</li> <li>Generating a thematic map of the analysis</li> </ul> |
| 5. Defining and naming themes | <ul style="list-style-type: none"> <li>Identifying the essence of each theme</li> </ul>                                                                                                                                                      |
| 6. Reporting                  | <ul style="list-style-type: none"> <li>Writing of a detailed analysis for each individual theme</li> <li>Relating data back to the research question and literature</li> </ul>                                                               |

#### 5.2.2 Interview analysis

Multiple main themes were discussed in the interviews. For each main theme, different sub-themes were identified through the thematic analysis of the interviews. Figure 9, Figure 10, and Figure 11 give the thematic maps of the different main themes discussed. The size of the words in which the sub-themes are displayed give an indication of in how many interviews the topic was mentioned. First, the themes given in Figure 9 are discussed. Then, the themes of opportunities and challenges are discussed in more depth, as the identification of the challenges and opportunities of flexible design was the main aim of the interviews. During the interviews, also multiple suggestions were done for possible considerations in the design process of a flexible floor system. Where applicable, these suggestions were included in the case study of Part III.

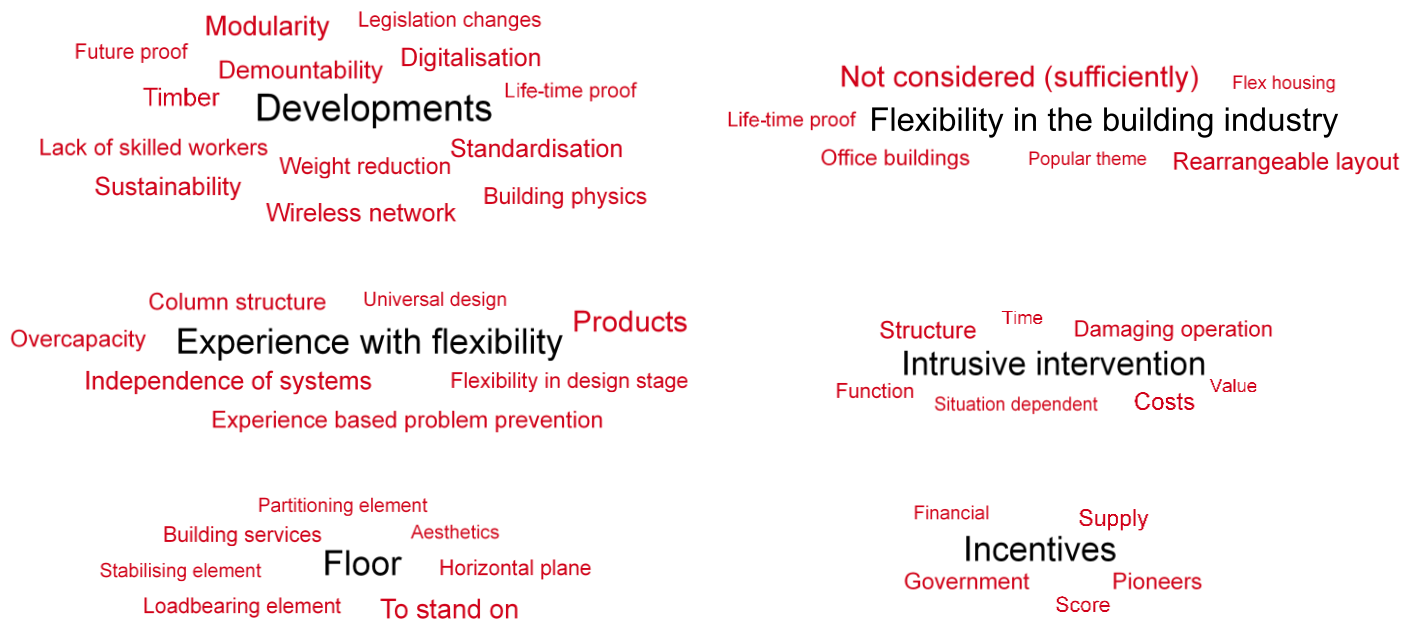


Figure 9: Thematic maps of the themes developments, flexibility in the building industry, experience with flexibility, intrusive intervention, floor, and incentives.

The “Developments” theme concerns the general developments in the building industry that are of interest to the different interviewees. Sustainability or circularity is mentioned as a topic of growing interest. Many of the other topics mentioned within this theme are also related to sustainable developments. Some of the other topics are more related to technological developments within the building industry.

As shown in the thematic map for “Flexibility in the building industry”, most interviewees note that flexibility is not or not sufficiently considered within the building industry. Several of the interviewees indicate that flexibility is more commonly considered in office buildings or utility buildings and that when flexibility is considered it usually concerns the rearrangeability of the layout of the building. In the discussion of their own experiences with flexible design in their work, several solutions are mentioned to increase the flexibility of the layout and use of a building. Both P5 and P6 specifically mention the prevention of integration of the building services with the load-bearing structure as a way to incorporate flexibility into their projects. Finally, several products that are available on the market that improve the flexibility of building are mentioned. Where relevant, these are included in the exploration of the existing flexible floor designs in Chapter 6.

For this thesis, flexibility of design is defined as the capacity of an object to adapt to changing circumstances and requirements without the need for intrusive interventions. The thematic map for “Intrusive intervention” shows the topics that came up when discussing what the interviewees would consider an intrusive intervention. For many of the interviewees how intrusive an intervention is, depends on the costs it incurs. Several interviewees indicate that an adaptation is always intrusive when the structure has to be adapted to facilitate a new functionality. There are also several interviewees that mention specific damaging operations that could cross the line for an intrusive intervention, such as the use of a concrete saw or grinding an opening into a building element. However, not all interviewees agree on the intrusiveness of different damaging operations.

The thematic map for “Floor” shows the topics that came up when the interviewees were asked what a floor was according to them. That a floor is something one stands or walks on was the most common response. This is in line with another response, that a floor is a load-bearing element. The horizontal orientation is also mentioned as a defining characteristic of a floor as well as its partitioning function.

On the topic of incentives, financial incentives were brought up as a stimulus that is always interesting and could also help establish flexible design in the building industry. The interviewees expect the introduction of a new design approach to entail some pioneering, both in the adoption of flexibility in the

design process and in the supply of flexible building elements. It was also mentioned that the government could provide incentives for the realisation of flexible design, either through subsidies or regulations. Another possible incentive mentioned is the introduction of a score that indicates the degree of flexibility of a building design. This could help designers get a grip of what flexible design is and how to incorporate it in their work and it could allow for flexibility to be included as a factor in the tendering process.



Figure 10: Thematic map of opportunities

Figure 10 gives the thematic map for the opportunities that flexible design has to offer. The most obvious advantage of flexible design of floor systems is the facilitation of changing requirements. P11 also mentions the advantage that if flexible design allows for adaptation without changes to the load-bearing structure, the risk of the adaptation is reduced and does not require a building permit. Flexibility is also of interest where it can contribute to sustainability ambitions. P4 notes that people are increasingly willing to invest in sustainable alternatives.

Flexible design can help make buildings future proof, by allowing the building to be adapted to future developments in the building industry and society. P9 mainly sees opportunities for flexible design in mixed-use buildings with both housing and enterprises. In this situation, the buildings can change along with the developments in society and provide more residential space when housing is necessary or provide company spaces when the demand in that area rises. The service life of real estate and how to keep their real estate portfolio relevant to future developments is of specific interest to professional investors. In addition, professional investors are more likely to understand and value the effect of their initial design investment in the long term. Finally, the topic of residual value can also be of interest to professional investors, as flexible design increases the chance of residual value at the end of a use cycle, either of the building as a whole or of the flexibly designed building elements. Overall, the interviews suggest that flexible design is probably more interesting to and more likely to catch on with professional investors than with private homeowners.

If flexible design is realised by reducing the direct integration of different functions, the workflows of the different disciplines are also less dependent. In this case, the processes required for the different disciplines can be independently optimised and time-consuming design iterations of one system as a result of changes in another system are no longer necessary. In addition, when a mistake has been made with the building services within the floor, it can currently take a lot of time and effort, and thus money, to find the mistake, hack open the floor, fix the mistake, and fix the floor again. With a flexible floor design, the solving of mistakes is simplified and the failure costs are reduced. Another way to make construction easier and cheaper, according to P7, is if systems are standardised and not uniquely designed for every project. This can be facilitated through flexible design.



Figure 11: Thematic map of challenges



Figure 11 illustrates the challenges the interviewees see for the implementation of flexible design in practice. Two main challenges were identified by most of the interviewees, these are the conservative culture within the building industry and the costs of implementing flexible design. The interviewees describe the building industry as conservative, traditional, cumbersome, and slow to adapt. They say that most builders tend to stick to what they know, using methods and systems they are familiar with to reduce risk, time investment, resistance from other parties, and questioning from subcontractors. As mentioned in the discussion of the incentives, getting new developments off the ground in the building industry requires parties willing to take on a pioneering role. Due to the slim margins within the industry, this willingness is not prevalent.

As a result of the slim margins in the building industry, the project budgets are limited. Among the interviewees, there is the expectation that flexible floor systems will be more expensive than traditional floors. For the traditional systems, the development costs and production investment costs are already amortised. This would not be the case for a new flexible floor design. In addition to the costs for the floor itself, other cost increases are also expected. Separation of functions within the floor is likely to increase the height of the floor. This could result in a higher building and thus more surface area of façade. A larger floor height could also mean that fewer stories, and thus less useable floor space, can be realised within the allotted building height. The building industry is a competitive business, so if flexible design is more expensive and the competitor uses traditional systems, the client needs to be aware of the added value of flexible design to be willing to invest. The designers themselves have no ownership over the project and are thus not incentivised to invest in flexibility.

The possibility that flexible design could require a higher initial investment and that that could form an obstacle to the realisation of flexible building design was also discussed in Chapter 2.3.2. Here, it was also discussed that taking into account the reduced reinvestment costs for adaptation and renovation, reduced maintenance costs, and increased service life could outweigh the increased initial investment costs. However, as discussed in the interviews the total cost of ownership is not sufficiently considered at the initial investment to let this shine through. P9 explains that they calculate their return figures over an exploitation period of 15 years.

The theme of legislation comes up in the interview in two different contexts. Legislation is mentioned with regard to height restrictions, in line with the expected increased height of flexible floor systems. The restrictions that are mentioned are both the maximum building height and the minimum space between two stories. Legislation is also mentioned with regard to the requirements for floors that need to be considered and the time and effort it requires to prove that a new floor system complies with all regulations.

### 5.2.3 Conclusions

The opportunities with regard to the implementation of flexibility measures in floor design at the end of the client mainly lie with its appeal to professional investors. Professional investors are more likely than private investors to understand and value the advantages of flexible floor design with regard to anticipating future developments and residual value. The increased interest in sustainability and the increased willingness to invest in sustainable alternatives is also a major opportunity for flexible floor systems as a more circular alternative to regular floor designs. For the building industry itself, the opportunities for the implementation of flexibility measures in floor systems lie with independent workflows of different disciplines, reduced failure costs, and the possibility to increase the standardisation of elements that can be used in multiple situations.

There are two major challenges for the implementation of flexibility measures in floor design. The first major challenge is the conservative nature of the building industry. The industry is hesitant to take on the risk of new developments, not to mention pioneering new developments. The second major challenge is the costs of flexible design. A new floor design is likely to be more expensive than the already amortised traditional floors. In addition, separation of functions is likely to increase the floor height which could lead to increased costs due to additional structure height and increased façade surface area or loss of revenue due to the reduced usable floor surface area within the allotted building height. The possibility that the reduced reinvestment costs for adaptation and renovation, reduced maintenance costs, and increased service life could outweigh the increased initial investment in the total cost of ownership is not included in this consideration.



### 5.3 Conclusions

Flexible floor design can be integrated in floor systems through the inclusion of the technical characteristics of flexible design. The technical characteristics of flexible design are the properties of a design that facilitate the technical flexibility of the floor. These characteristics are accessibility, durability, independence, integration, interface simplicity, overcapacity, and standardisation.

The opportunities for flexible design that the floor design should capitalise on lie with sustainability and adaptability to future developments, from the perspective of the client, and with workflow independence, reduction of failure costs, and increased opportunities for standardisation, from the perspective of the industry. The effect of design choices, such as floor height, on the costs of a building project should be taken into consideration in the floor design.

## 6 Existing solutions

To answer the second sub-question, first, the different existing designs for flexible floor systems are identified through a literature study. These designs and their properties are then compared with the results of the first sub-question to determine which flexibility measures are included in the existing floor designs and what their advantages and drawbacks are.

The approach for the literature study can be found in Appendix C. From the literature study, a distinction can be made between the floor systems with the building services integrated within the structural floor height and floor systems that keep the structural floor and the buildings services completely separated. The existing designs for floor types from categories are discussed in this chapter.

### 6.1 Floors with integrated building services

Different designs for floor systems that integrate building services and allow for adaptation and flexibility after construction were identified in the literature study. These floor systems can be divided into two categories. In the first category, floors have been fitted with grooves through which piping can be laid. The second category contains floors that have a hollow space within the floor height that can be used for the placement of piping and other building service facilities. The two categories of floors are illustrated in Figure 12. The designs of the different floors in both categories are discussed in the following paragraphs.



Figure 12: Schematisation of the groove floor category (left) and the hollow floor category (right)

#### 6.1.1 Floors with grooves

The existing floor designs that incorporate grooves for the integration of building services are variations of the widely applied hollow core slab.

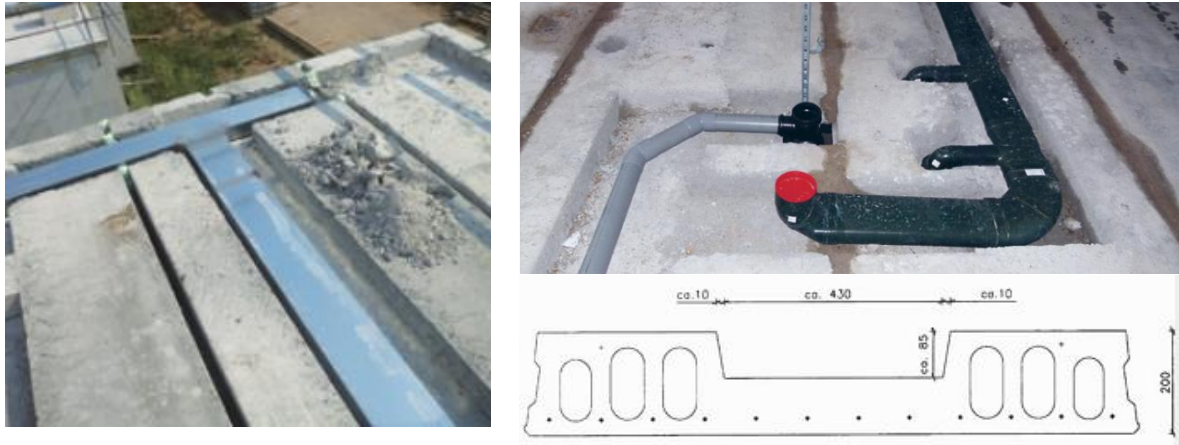


Figure 13: Dycore piping floor, left and top right (Dycore, 2016), bottom left (den Boon & Fraanje, 2007)

The Dycore piping floor, as shown in Figure 13, has been developed for the application of hollow core slabs in ground-level housing (Dycore, 2016). In the factory, grooves can be made for the placement of ventilation or sewerage channels in both directions of the floor (den Boon & Fraanje, 2007; Dycore, 2016). At the cross-section where the grooves are placed, the floor is a 115 mm high solid reinforced concrete slab, as can be seen in the bottom left of Figure 13 (den Boon & Fraanje, 2007). After the pipes have been laid, the grooves do not have to be filled structurally, a low-grade sand-cement mortar is sufficient (den Boon & Fraanje, 2007; Dycore, 2016). This way, the grooves can be scraped open relatively easily to adapt the layout of the pipes later on (Dycore, 2016).

In principle, the layout of the piping should be known before production. However, the floor can be used more flexibly when extra grooves are made (den Boon & Fraanje, 2007). This way, the final layout of the piping can be decided later on. If the extra grooves are covered, for example with a wooden plate, they can also be utilized for changes during the use phase of the building (den Boon & Fraanje, 2007).

Table 4: Product information Dycore piping floor

| Dycore piping floor |                                                   |                                          |
|---------------------|---------------------------------------------------|------------------------------------------|
| Span                | up to ca. 9 m                                     | (Dycore, 2016)                           |
| Height              | 150 - 400 mm                                      | (den Boon & Fraanje, 2007; Dycore, 2016) |
| Own weight          | 249 - 510 kg/m <sup>2</sup> (incl. joint filling) | (Dycore, 2016)                           |
| Fire safety         | 60 min. fire resistant                            | (den Boon & Fraanje, 2007)               |

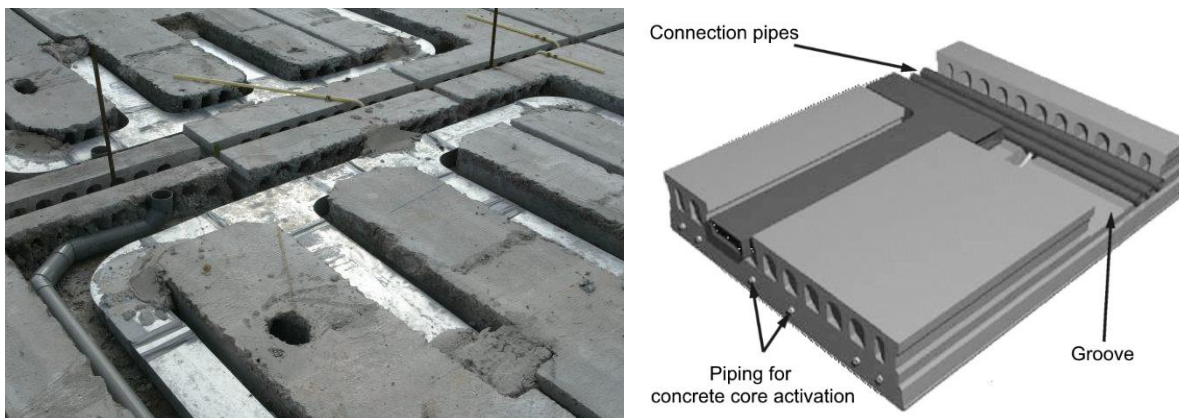


Figure 14: VBI piping floor, left (den Boon & Fraanje, 2007), right adapted from 'VBI Klimaatvloer' (Dreßen, 2011)

The VBI piping floor, shown in Figure 14, consists of a prefabricated prestressed hollow core slab, of which the bottom slab has been increased in thickness so that grooves can be made in the top slab (Consolis VBI, n.d.-c; den Boon & Fraanje, 2007; Dreßen, 2011). To ensure the load-bearing capacity of the floor, the grooves are restricted to a predetermined pattern (Consolis VBI, n.d.-c; Dreßen, 2011). After the piping is placed, concrete is poured into the grooves on site (Dreßen, 2011). The VBI piping floors are mainly used in terraced housing as storey floors, self-supporting floors, or roof floors (Consolis VBI, n.d.-c). With the use of a screed placed on springs, the requirements for house separating floors can also be met (Consolis VBI, n.d.-c).

The grooves in the floor are premade in the factory (Consolis VBI, n.d.-c). For optimal flexibility, a ring groove can be made around the entire floor area, providing maximum freedom for the future configuration of the building, as illustrated in Figure 15. The floor is flexible in the design and construction phase, and depending on the screed used also in the use-phase (Consolis VBI, n.d.-c; den Boon & Fraanje, 2007). Because the reduced strength due to the grooves is incorporated in the strength calculation, the grooves can be filled with a non-structural filling. Because of this, the piping remains reasonably accessible and individual user options can be applied throughout the years of use (den Boon & Fraanje, 2007).

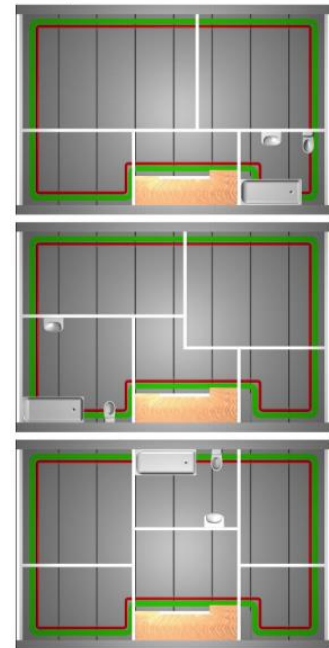


Figure 15: Flexible layout due to ring groove (Consolis VBI, n.d.-c)

Table 5: Product information VBI piping floor

| VBI piping floor |                                                                                                                                              |                                |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Span             | up to 9.0 m                                                                                                                                  | (Consolis VBI, n.d.-d)         |
| Height           | 200 mm for spans of up to 7.6 m<br>260 mm for spans of up to 9.0 m                                                                           | (Consolis VBI, n.d.-c, n.d.-d) |
| Own weight       | 386 kg/m <sup>2</sup> (incl. joint filling) for spans of up to 7.6 m<br>511 kg/m <sup>2</sup> (incl. joint filling) for spans of up to 9.0 m | (Consolis VBI, n.d.-c, n.d.-d) |
| Fire safety      | 90 min. fire resistant for spans of up to 7.6 m<br>120 min. fire resistant for spans of up to 9.0 m                                          | (Consolis VBI, n.d.-c, n.d.-d) |

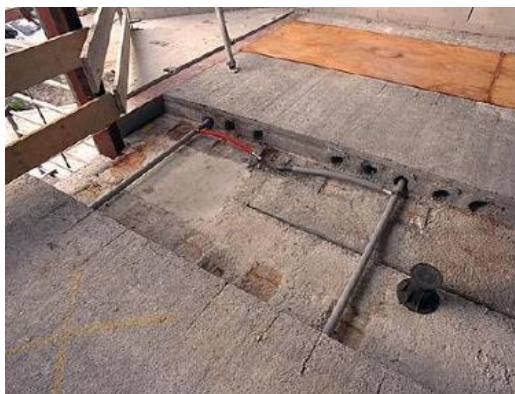


Figure 16: Wing floor (den Boon & Fraanje, 2007)

The wing floor system shown in Figure 16 consists of a 1200 mm wide hollow core slab in the middle, with on both sides 600 mm wide “wings” of precast lattice slabs (den Boon & Fraanje, 2007). In the traverse direction, there are a couple of channels through which piping can be laid and when two wing floors are put next to each other on site, a groove of 1200 mm is formed in the span direction (den Boon & Fraanje, 2007). Depending on the functional and structural requirements, the groove can either be filled with a structural reinforced concrete layer, a non-structural mortar, or be covered with a sheet material (den Boon & Fraanje, 2007).

Table 6: Product information wing floor

| Wing floor  |                                                   |                                             |
|-------------|---------------------------------------------------|---------------------------------------------|
| Span        | 6 - 16 m                                          | (Beton Son, 2003; den Boon & Fraanje, 2007) |
| Height      | 180 - 420 mm                                      | (Beton Son, 2003; den Boon & Fraanje, 2007) |
| Own weight  | 225 - 427 kg/m <sup>2</sup> (incl. joint filling) | (Beton Son, 2003; den Boon & Fraanje, 2007) |
| Fire safety | Standard 60 min. fire resistance                  | (Beton Son, 2003)                           |

### 6.1.2 Hollow floors

A wide variety of floors have been designed that incorporate building services in a hollow space within the structural height of the floor. The different designs focus on different aspects, such as floor height or weight.

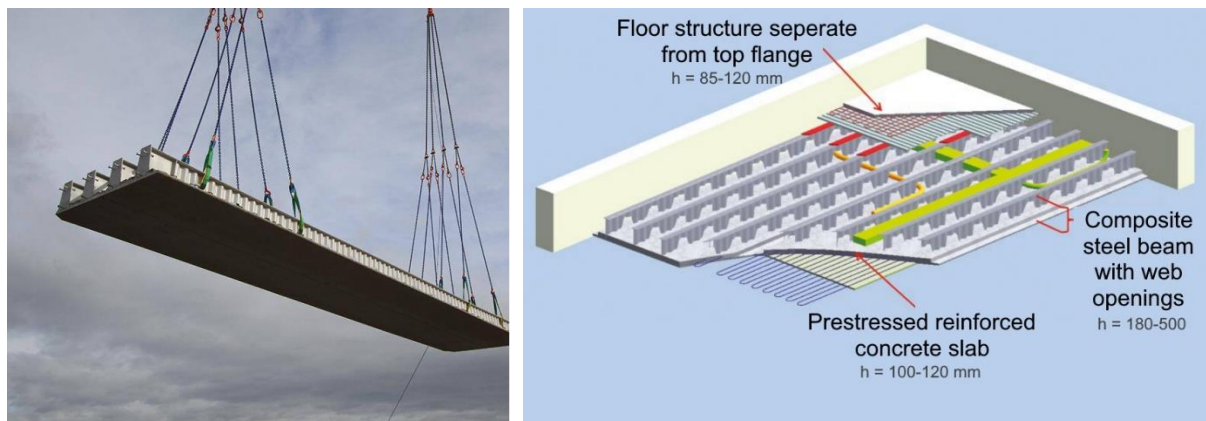


Figure 17: CLC multifunctional floor, left (Franz Oberndorfer GmbH, n.d.), right adapted from ‘Die CLC-Multifunktionsdecke als 3-Zonen-Deck’ (Olipitz, 2017)

The CLC multifunctional floor system, shown in Figure 17, is a composite structure consisting of a prestressed reinforced concrete slab with a corrugated steel beam with web openings, and a floor structure on top that is separated from the steel top flange (Franz Oberndorfer GmbH, n.d.; Olipitz, 2017). The concrete slab in the tension zone remains without cracks due to the prestressing and can be used as a structural plate to stiffen the building (Franz Oberndorfer GmbH, n.d.). This combination of elements results in a high degree of material efficiency (Olipitz, 2017). All the connection details of the prefabricated elements are standardized, they have a system width of 2.40 m and are structurally connected with grout joints (Franz Oberndorfer GmbH, n.d.).

The hollow space between the concrete slab and the floor structure accommodates building services (Franz Oberndorfer GmbH, n.d.; Olipitz, 2017). The available space in the longitudinal direction between the corrugated steel beams has a width of 480 to 600 mm and a height of 180 to 500 mm, depending on the element type. In the transversal direction, the available space is limited by the web openings and is 200 mm wide and 80 to 250 mm high depending on the element type (Olipitz, 2017). For a bigger span, and thus a bigger floor height, the flexibility of building service integration increases. The concrete slab



on the bottom is also suitable for thermal activation for cooling and heating of the building (Franz Oberndorfer GmbH, n.d.).

The floor system on top has to be flexible in order to facilitate accessibility and adaptability of the building services. This flexible floor system consists of concrete plates of 600 by 600 mm with a thickness of at least 40 mm that are placed on top of adjustable feet that allow for level adjustment (Olipitz, 2017). This is called the bare floor. On the bare floor, an insulation mat is placed, which decouples the concrete plates from the plasterboards screwed on top (Olipitz, 2017).

Table 7: Product information CLC multifunctional floor

| CLC multifunctional floor |                             |                 |
|---------------------------|-----------------------------|-----------------|
| Span                      | 6 – 16 m                    | (Olipitz, 2017) |
| Height                    | 400 - 720 mm                | (Olipitz, 2017) |
| Own weight                | 280 - 300 kg/m <sup>2</sup> | (Olipitz, 2017) |

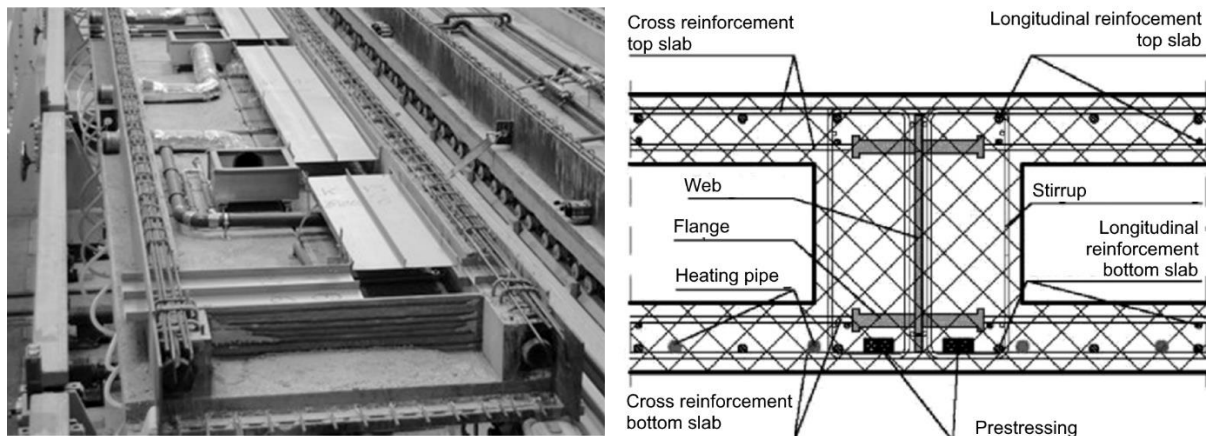


Figure 18: Con4 floor, left (Dreßen, 2011), right adapted from 'Querschnitt Con4-Decke an der Vergussfuge' (Kuhlmann, 2010)

The Con4 sandwich floor system consists of two thin 10 cm thick concrete slabs and a steel web that connects the two and creates a hollow space of 20 cm high that provides room for building services (Dreßen, 2011; Kuhlmann, 2010). Openings in the steel webs make individual routing of the pipes possible (Dreßen, 2011). These openings can have the same height as the space between the concrete slabs (Dreßen, 2011; Kuhlmann, 2010). Access to the building services in the floor is only possible via the inspection openings in the top floor slab (Dreßen, 2011).

For the load-bearing capacity and to create a shear-proof connection between the web and the slabs, steel girders with laterally welded headed bolt dowels are arranged in the webs as a means of bonding (Dreßen, 2011; Kuhlmann, 2010). To ensure, in addition to the load-bearing capacity, also the serviceability of such a slender structure, prestressing is applied in the bottom floor slab (Kuhlmann, 2010).

Table 8: Product information Con4 floor

| Con4 floor  |            |                  |
|-------------|------------|------------------|
| Span        | up to 16 m | (Dreßen, 2011)   |
| Height      | 400 mm     | (Kuhlmann, 2010) |
| Fire safety | REI 90     | (Kuhlmann, 2010) |

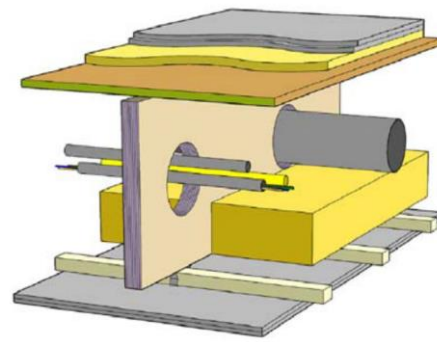


Figure 19: Flexvloer (den Boon & Fraanje, 2007)

The Flexvloer is a wooden floor system, designed for application in residential and utility buildings (den Boon & Fraanje, 2007). The floor consists of laminated veneer lumber ribs and slabs which are glued together to create a stiff floor element (den Boon & Fraanje, 2007; Wang, 2019). The lightweight floor system can comply with the Building Decree requirement for home separating walls when a floating screed and a freely suspended ceiling is applied (den Boon & Fraanje, 2007). The building services incorporated in the floor are accessible both from the bottom and the top of the floor (den Boon & Fraanje, 2007; Wang, 2019).

Table 9: Product information Flexvloer

| Flexvloer     |                                                                                        |                            |
|---------------|----------------------------------------------------------------------------------------|----------------------------|
| Span          | 7 - 8 m                                                                                | (den Boon & Fraanje, 2007) |
| Height        | 385                                                                                    | (den Boon & Fraanje, 2007) |
| Own weight    | 30 kg/m <sup>2</sup>                                                                   | (den Boon & Fraanje, 2007) |
| Load capacity | Permanent load: max. 70 kg/m <sup>2</sup><br>Variable load: max. 175 kg/m <sup>2</sup> | (den Boon & Fraanje, 2007) |

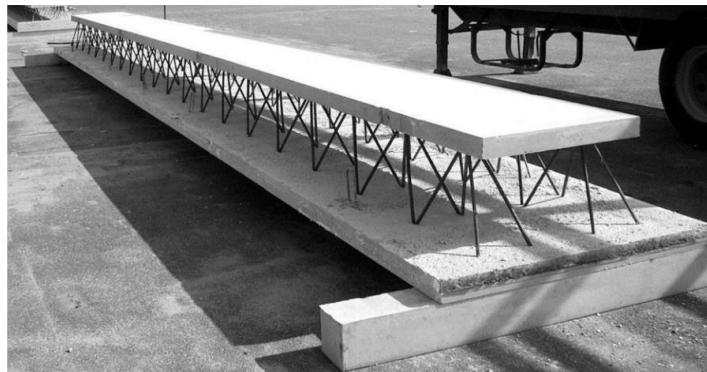


Figure 20: HOLCON floor (Holcon B.V., n.d.), right (Dreßen, 2011)

The HOLCON floor system consists of two 13 cm thick concrete slabs which are connected by lattice girders to form floor elements of 1.80 m wide (Dreßen, 2011). The reinforcement bars of the lattice girder have a diameter of 10 to 40 mm, allowing for spans of up to 18 m with a structural height of 70 cm (Dreßen, 2011). The top slab is 50 cm less wide than the bottom slab, allowing for building services to be easily installed from the top. The gaps are closed off using calcium sulphate plates to ensure accessibility for changes and maintenance of the building services (Dreßen, 2011). On site, the top slab of the floor element is placed on edge beams to install the floors. To create a diaphragm, the elements are connected to each other using steel anchor plates embedded in the concrete (Dreßen, 2011).

Table 10: Product information HOLCON floor

| HOLCON floor |                       |                                   |
|--------------|-----------------------|-----------------------------------|
| Span         | up to 18 m            | (Dreßen, 2011)                    |
| Height       | 700 mm                | (Dreßen, 2011; Holcon B.V., n.d.) |
| Own weight   | 500 kg/m <sup>2</sup> | (Holcon B.V., n.d.)               |

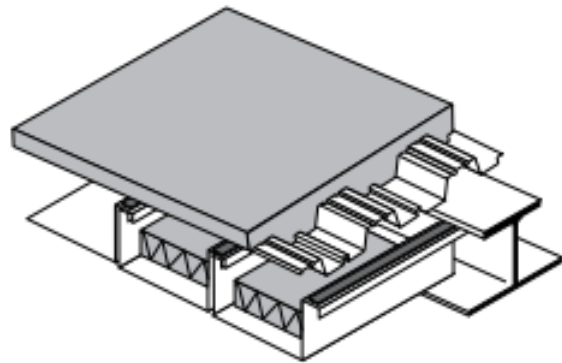


Figure 21: Ides floor, left (den Boon & Fraanje, 2007), right (Bouwen met Staal, 2013)

The Ides (Integrated Deck Extra Space) floor is built up out of steel elements. The system consists of an asymmetrical I-beam, with a wider lower flange, that contains large U-profiles (den Boon & Fraanje, 2007). The U-profiles can be filled with insulation material and piping. A profiled steel plate is placed on top of rubber granulate on the I-beams and U-profiles, alternatively, a multiplex plate can be used (den Boon & Fraanje, 2007). Finally, a screed is placed on top, which can be a compressed wooden plate or an anhydrite poured screed. The latter does reduce the flexibility and the fully demountable properties of the system (den Boon & Fraanje, 2007).

In the screed, hatches or grates can be incorporated to keep the building services accessible. The floor is designed to be as light and thin as possible; the flexibility of the building services is not a priority but an added bonus. The U-profiles facilitate the building services nicely in one direction, but in the other direction limited openings can be made and they can only be placed where the floor is supported (den Boon & Fraanje, 2007)

Table 11: Product information Ides floor

| Ides floor       |                                                          |                            |
|------------------|----------------------------------------------------------|----------------------------|
| Span             | up to 7.2 m                                              | (den Boon & Fraanje, 2007) |
| Height           | 250 - 400 mm                                             | (den Boon & Fraanje, 2007) |
| Own weight       | 50 kg/m <sup>2</sup>                                     | (den Boon & Fraanje, 2007) |
| Fire safety      | standard 30 min. fire resistant, up to 120 min. possible | (den Boon & Fraanje, 2007) |
| Sound insulation | R <sub>w</sub> = 50 dB                                   | (den Boon & Fraanje, 2007) |



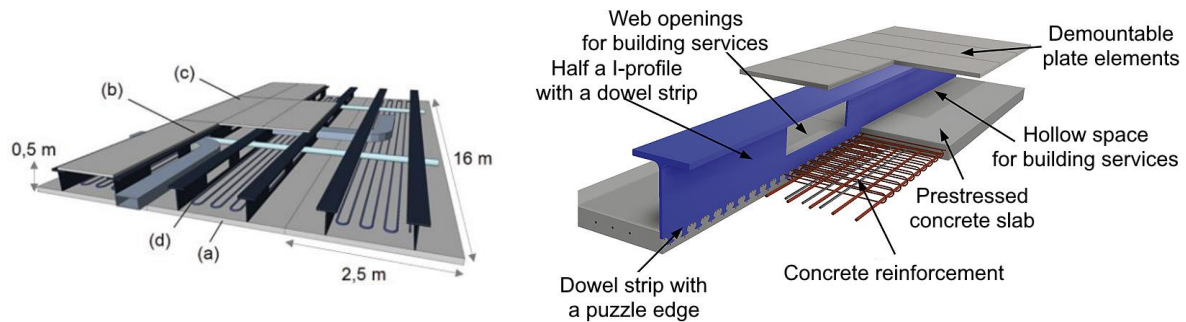


Figure 22: InaDeck, left (Hegger et al., 2014), right adapted from 'Überblick über das integrierte und nachhaltige Deckensystem InaDeck' (Schaumann et al., 2019)

The InaDeck floor system is a steel-concrete composite structure (Hegger et al., 2014). It consists of a prestressed concrete slab in the tension zone of the cross-section which is connected to an uncovered half I-profile through a glued dowel strip in a puzzle or Euler spiral shape (Hegger et al., 2014; Schaumann et al., 2019). On top of the I-profile, removable panel elements are placed (Schaumann et al., 2019). For the flexibility of the piping, large openings are made in the web of the steel I-profile (Hegger et al., 2014). Proper accessibility of the hollow space and easy installation and maintenance of the buildings services is realised through removable panels at the top of the cross-section (Hegger et al., 2014). Because of the prestressed concrete at the bottom, the floor combines good building physics qualities and fire safety properties with a large span and a high degree of flexibility (Hegger et al., 2014). The concrete slab can also be thermally activated (Hegger et al., 2014; Schaumann et al., 2019).

Table 12: Product information InaDeck

| InaDeck       |                           |                                               |
|---------------|---------------------------|-----------------------------------------------|
| Span          | 12 - 16 m                 | (Hegger et al., 2014; Schaumann et al., 2019) |
| Load capacity | up to 5 kN/m <sup>2</sup> | (Hegger et al., 2014; Schaumann et al., 2019) |
| Fire safety   | R90                       | (Schaumann et al., 2019)                      |

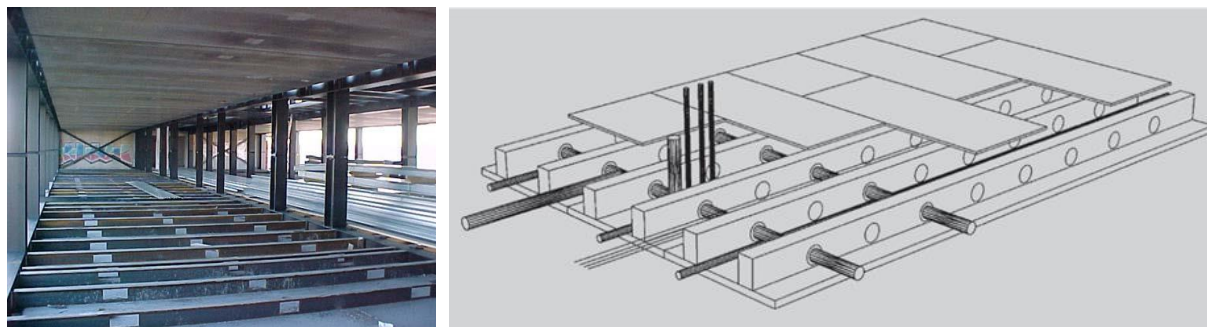


Figure 23: Infra+ floor, left (den Boon & Fraanje, 2007), right (Meijer, 1998)

The infra+ floor system is a prefabricated composite structure with a system width of 2.40 m (Dreßen, 2011). It consists of steel profiles with web openings, of which the bottom flanges are cast into a 70 mm thick concrete slab (den Boon & Fraanje, 2007; Meijer, 1998; Wang, 2019). The space between the steel profiles and through their openings can be used for the routing of piping (Dreßen, 2011; Meijer, 1998). The concrete slab at the bottom mainly serves to meet the building physics requirements, to separate spaces, and to act as a floor on which the building services can be placed (Dreßen, 2011). On top of the steel profiles, rubber strips are placed, on which a profiled steel sheet is placed (den Boon & Fraanje, 2007; Wang, 2019). This steel sheet is either covered with demountable plate materials or with a screed of anhydrite or sand cement (den Boon & Fraanje, 2007; Meijer, 1998; Wang, 2019). If a demountable screed is used, the building services remain accessible (Meijer, 1998).

Table 13: Product information Infra+ floor

| Infra+ floor |                                           |                                        |
|--------------|-------------------------------------------|----------------------------------------|
| Span         | up to 12 m                                | (Dreßen, 2011)                         |
| Height       | 280 mm for a span of 5.4 m                | (den Boon & Fraanje, 2007; Wang, 2019) |
| Own weight   | 300 kg/m <sup>2</sup> for a span of 5.4 m | (den Boon & Fraanje, 2007; Wang, 2019) |
| Fire safety  | 145 min. fire resistant                   | (den Boon & Fraanje, 2007; Wang, 2019) |

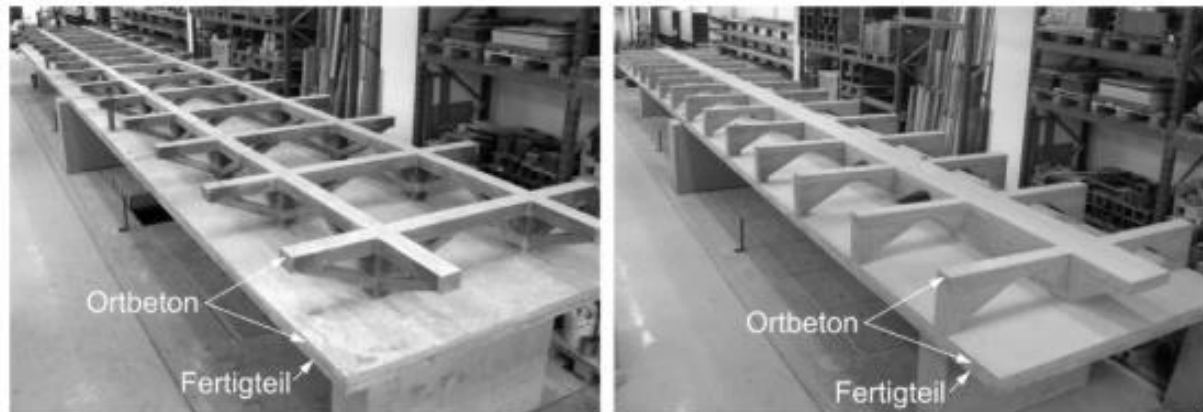


Figure 24: Floor system developed by TU Wien (Dreßen, 2011)

The floor system shown in Figure 24, was developed by the Institute for Supporting Structures of TU Wien (Dreßen & Hegger, 2010). It consists of a 10 cm thick slab of reinforced concrete at the bottom and ribs of reinforced concrete connected crosswise at the top. To facilitate the integration of building services within the structural height of the floor, the reinforced concrete ribs are placed into a framework structure with a continuous upper beam (Dreßen, 2011). The fire safety requirements for the floor are met due to the 10 cm thick bottom slab. The noise reduction properties of the floor are comparable to those of a 30 cm high cast in situ concrete slab (Dreßen, 2011). The accessibility of the building services in the hollow space can be assured through the use of a removable screed.

Table 14: Product information floor system developed by TU Wien

| Floor system developed by TU Wien |           |                |
|-----------------------------------|-----------|----------------|
| Span                              | 16 x 16 m | (Dreßen, 2011) |
| Height                            | 900 mm    | (Dreßen, 2011) |



Figure 25: Lignatur, left (den Boon & Fraanje, 2007), right (Lignatur, 2019)

Lignatur elements are industrially made wooden structural components. Wooden lamellae are used to make hollow channels which are combined into a wooden hollow core slab (den Boon & Fraanje, 2007). With the Lignatur floor system, large spans can be achieved and high loads can be carried with a minimal floor height (den Boon & Fraanje, 2007). In the longitudinal direction, piping is easily integrated. In the transversal direction, the placement of piping is only possible through added openings with a small diameter (den Boon & Fraanje, 2007). To ensure continued accessibility of the building services, a removable screed should be applied.

Table 15: Product information Lignatur

| Lignatur         |                                                                    |                                            |
|------------------|--------------------------------------------------------------------|--------------------------------------------|
| Span             | up to 12 m (LKE)<br>up to 16 m (FLE)                               | (den Boon & Fraanje, 2007)                 |
| Height           | 120 - 320 mm                                                       | (den Boon & Fraanje, 2007; Lignatur, 2014) |
| Own weight       | 37 - 68 kg/m <sup>2</sup> (LKE)<br>33 - 48 kg/m <sup>2</sup> (FLE) | (den Boon & Fraanje, 2007; Lignatur, 2014) |
| Fire safety      | 90 min fire resistant (LKE)<br>30 min fire resistant (FLE)         | (den Boon & Fraanje, 2007)                 |
| Noise insulation | 32 dB for 200 mm height (LKE)                                      | (den Boon & Fraanje, 2007)                 |

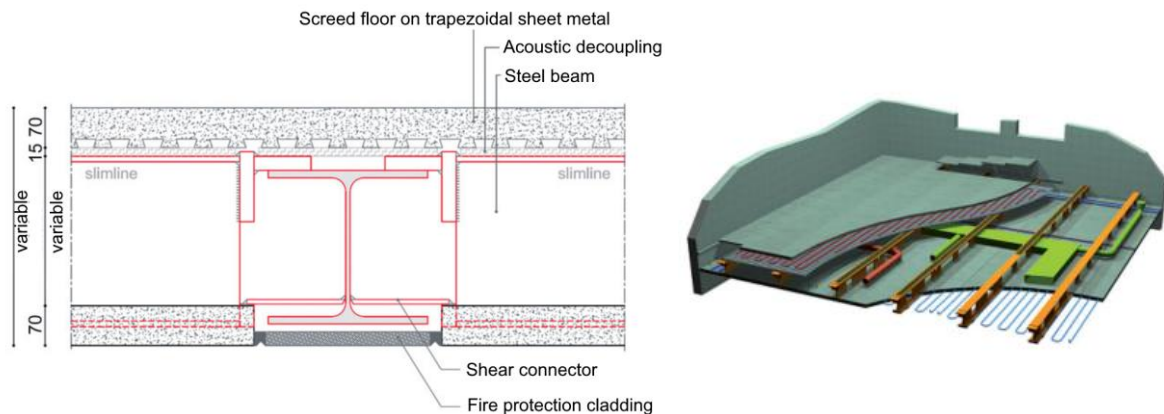


Figure 26: Slimline floor, left adapted from 'Lagerung der Deckenelemente mit Auflagerknaggen' (Mensing et al., 2010), right (Mensing et al., 2010)

The Slimline floor is a prefabricated steel-concrete solution (Mensing et al., 2010). It consists of supporting steel beams, which contain a standard pattern of openings, integrated into a 70 mm thick concrete slab (Mensing et al., 2010; Wang, 2019). The concrete slab is not prestressed (Olipitz, 2017). The floor can be topped with a screed of choice (Wang, 2019). The concrete slab mainly acts as a separator of spaces for noise and fire safety and can be thermally activated (Mensing et al., 2010).

Table 16: Product information Slimline floor

| Slimline floor   |                                                                                             |                                         |
|------------------|---------------------------------------------------------------------------------------------|-----------------------------------------|
| Span             | up to 16.2 m                                                                                | (Slimline Buildings BV, n.d.-b)         |
| Height           | ca. 420 mm incl. screed for a span of 7.2 m<br>ca. 720 mm incl. screed for a span of 16.2 m | (Slimline Buildings BV, n.d.-b, n.d.-a) |
| Own weight       | 312 kg/m <sup>2</sup>                                                                       | (Slimline Buildings BV, n.d.-a)         |
| Fire safety      | 145 min. fire resistant                                                                     | (Wang, 2019)                            |
| Noise insulation | 10 dB                                                                                       | (Wang, 2019)                            |



Figure 27: Starframe floor, left (den Boon & Fraanje, 2007), right (TataSteel, 2011)

Corus Starframe develops steel construction components for application in steel frame structures (den Boon & Fraanje, 2007). Their Starframe floor elements consist of a steel frame, usually executed in C200 profiles, built up out of beams and intermediate connecting beams or strips (den Boon & Fraanje, 2007). In the beams, openings with a 130 mm diameter are placed in the zones with reduced bending moments (TataSteel, 2011). These openings can be used for the routing of piping and cables. The bottom side of the frame is covered by gypsum cardboard panels fastened with screws and provides a reasonable degree of accessibility to the hollow space in the floor element (den Boon & Fraanje, 2007). The top of the floor can be covered with either a wooden panel or a profiled steel sheet covered with anhydrite, depending on the functional requirements (TataSteel, 2011).

Table 17: Product information Starframe

| Starframe  |                                                                                                           |                                             |
|------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------|
| Span       | 4.5 - 7.2 m                                                                                               | (TataSteel, 2011)                           |
| Height     | 242 mm with a wooden plate screed<br>256 mm with an anhydrite screed                                      | (TataSteel, 2011)                           |
| Own weight | ca. 75 kg/m <sup>2</sup> with a wooden plate screed<br>ca. 100 kg/m <sup>2</sup> with an anhydrite screed | (den Boon & Fraanje, 2007; TataSteel, 2011) |



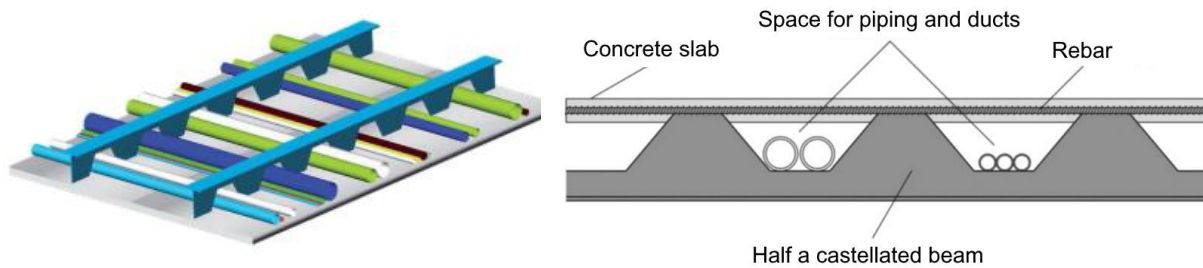


Figure 28: Topfloor, left (Mensingher et al., 2010), right adapted from 'Konstruktionsprinzip Topfloor integral in Positivlage' (Mensingher et al., 2010)

The Topfloor integral floor system has been developed by EHT Zurich and the Swiss steel construction company H. Wetter AG (Dreßen, 2011; Mensinger et al., 2010; Olipitz, 2017). The floor system employs half a castellated beam instead of the more commonly applied I-profile, in combination with a 10 cm thick concrete slab (Dreßen, 2011; Mensinger et al., 2010). The concrete slab is not prestressed (Olipitz, 2017). The castellated beams are placed at 1.25 m intervals and are attached to the concrete rebar through a welded shear-proof connection (Dreßen, 2011). The floor can be placed in a negative position, with the concrete slab at the bottom, and in a positive position, with the concrete slab at the top (Mensingher et al., 2010). This can be useful for meeting specific fire safety requirements (Mensingher et al., 2010). The openings in the castellated beam make flexible building service integration possible and result in a high material efficiency (Mensingher et al., 2010). It is possible to incorporate thermal activation of the concrete slab (Mensingher et al., 2010)

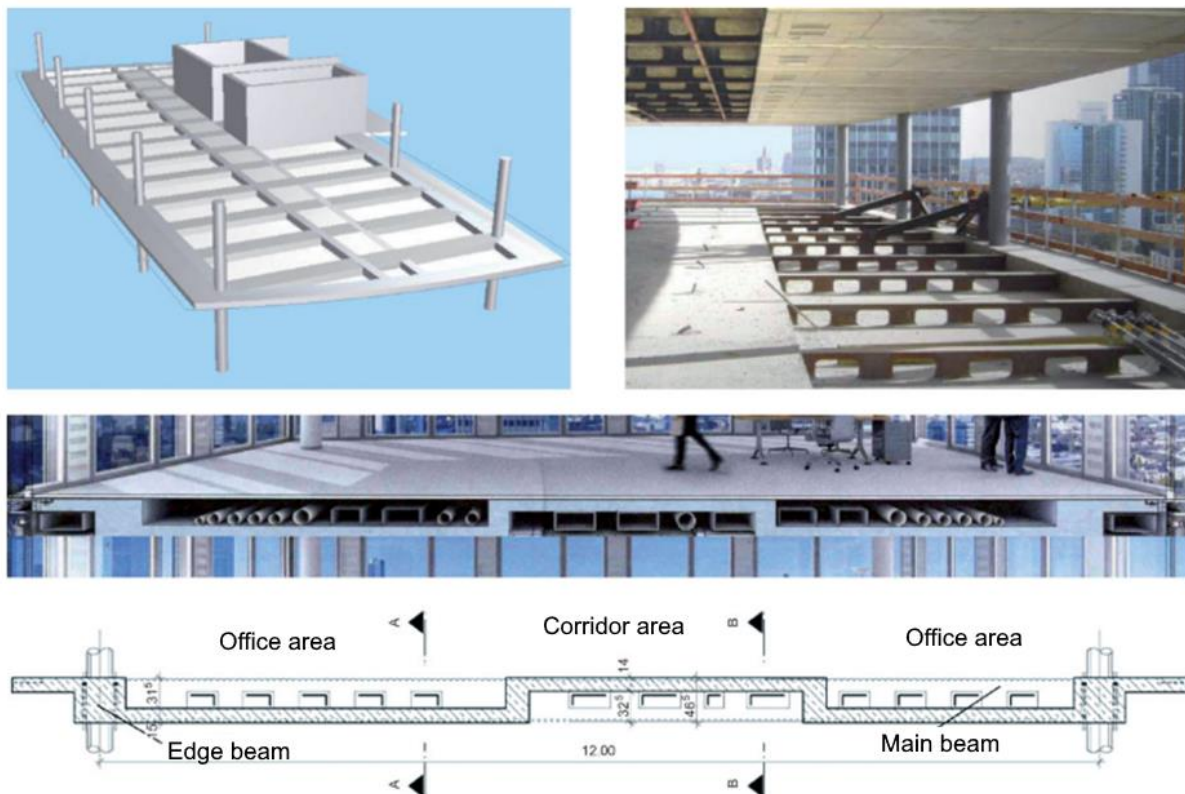


Figure 29: WestendDuo floor system, adapted from 'Gefaltete Decke bei Hochhaus WestendDuo in Frankfurt am Main' (Mensingher et al., 2010)

With the aim to optimize the structural height, an integrated floor system has been developed for the WestendDuo building in Frankfurt am Main (Mensingher et al., 2010). The idea behind the design is to integrate both the upper and lower building services levels in the structural height of the floor. The non-prestressed, cast-in-situ floor has a thickness of 15 cm (Mensingher et al., 2010). At the outside of the

building, this slab is located at the bottom of the floor, but in the middle of the building the concrete slab ‘jumps up’. The advantage of this jump is that building services that belong to a certain floor do not need to be laid through structural openings that can form a problem for noise reduction and fire safety requirements (Mensingher et al., 2010). The concrete slab forms the separation of spaces and is compliant with the requirements for noise reduction and fire resistance. In addition, the concrete slab functions as a diaphragm (Mensingher et al., 2010).

Table 18: Product information WestendDuo floor

| WestendDuo floor |          |                           |
|------------------|----------|---------------------------|
| Span             | ca. 12 m | (Mensingher et al., 2010) |
| Fire safety      | R120     | (Mensingher et al., 2010) |

### 6.2 Floors with separated building services

When the building services are separated from the structural floor, the building services are either placed on top of the floor in a raised floor system or below the floor in a suspended ceiling system.



Figure 30: Raised floor system, left (Wu et al., 2017), right (Wang, 2019)

Raised floor systems are commonly applied in office buildings and data centres (Wang, 2019). The system typically consists of load-bearing floor panels, which are spread out in a horizontal grid and are supported at each corner by adjustable pedestal jacks (Wu et al., 2017). Generally, the panels are 600 mm by 600 mm and made of particleboard, plywood, aluminium, steel, or a combination of metal and non-metal. Particleboard or plywood is usually covered with a thin steel or aluminium sheet for fire protection (Wu et al., 2017). The vertical pedestals are placed on the structural floor and provide an underfloor space for the placement of building services (Nederlands Normalisatie-instituut, 2001; Wu et al., 2017). The floor panels can be lifted easily, granting full access to the services in the underfloor space (Nederlands Normalisatie-instituut, 2001; Wang, 2019; Wu et al., 2017). This provides a high degree of flexibility in the design and layout of the services routed below the floor panels (Wu et al., 2017). However, raised floors do often result in a larger total height of the floor than other systems (Wang, 2019).



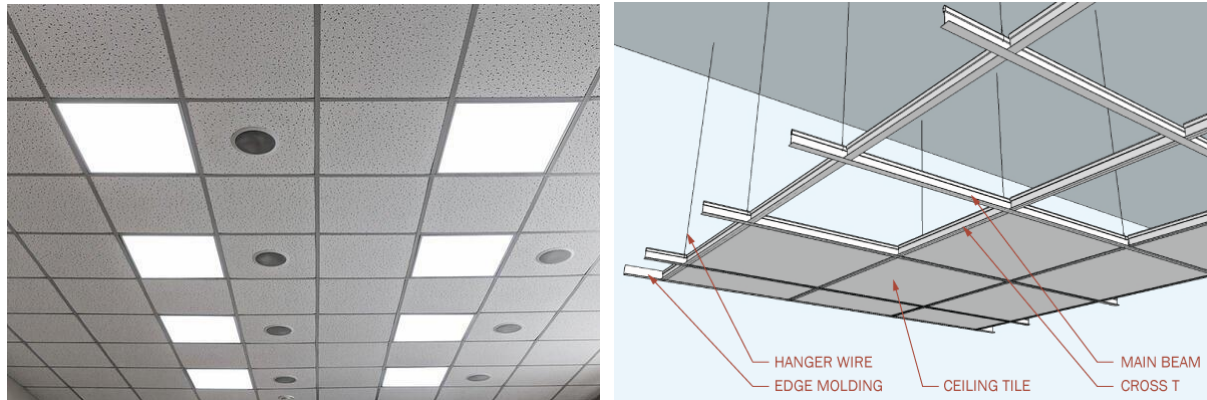


Figure 31: Suspended floor system, left (Muresan, 2021), right (Archtoolbox, 2020)

Suspended ceilings are non-structural elements that are widely used in commercial and residential buildings to serve as a barrier between the building services underneath the floor slab and the space below (Bannister, 1985; Soroushian et al., 2015). The barrier has an aesthetic function but is also of importance for acoustic control, fire protection and thermal insulation (Bannister, 1985). The ceiling system consists of an interlocking grid of inverted tee beams, suspended from the load-bearing structure above (Nederlands Normalisatie-instituut, 2014; Soroushian et al., 2015). On top of the flanges of the tee beam grid, the ceiling tiles are placed. Usually, the tiles are simply resting on top of the flanges and are not locked into place, ensuring removability and accessibility of the building services. (Bannister, 1985; Soroushian et al., 2015). The ceiling tiles are generally made of a compressed high-density mineral fibre material (Soroushian et al., 2015).

### 6.3 Comparison of floor designs

To provide insight into the product properties, the height-to-weight ratio of the found floor systems are compared to each other and to the most commonly applied floor systems in residential buildings. The two main floor systems used for storey floors in Dutch residential buildings are precast lattice slabs and hollow core slabs (van Paassen et al., n.d.). Typically, residential buildings have a spacing grid of either 5.4 or 7.2 m (Remøy & van der Voordt, 2011). For the comparison of the floor systems, a span of 7.2 m is assumed. Figure 32 shows the relation between the height and the weight of the floor systems for a span of 7.2 m. The data used is based on the information gathered in the previous paragraphs and manufacturer product information for the precast lattice slab and the hollow core slab (Consolis VBI, n.d.-b; Van Nieuwpoort Prefab Beton, n.d.). For the hollow core slab and hollow core slab derivatives, a structural topping of 60 mm is assumed (Mones & Breña, 2013). Not all flexible floor systems found are included, as the relevant information was not available for all of them.

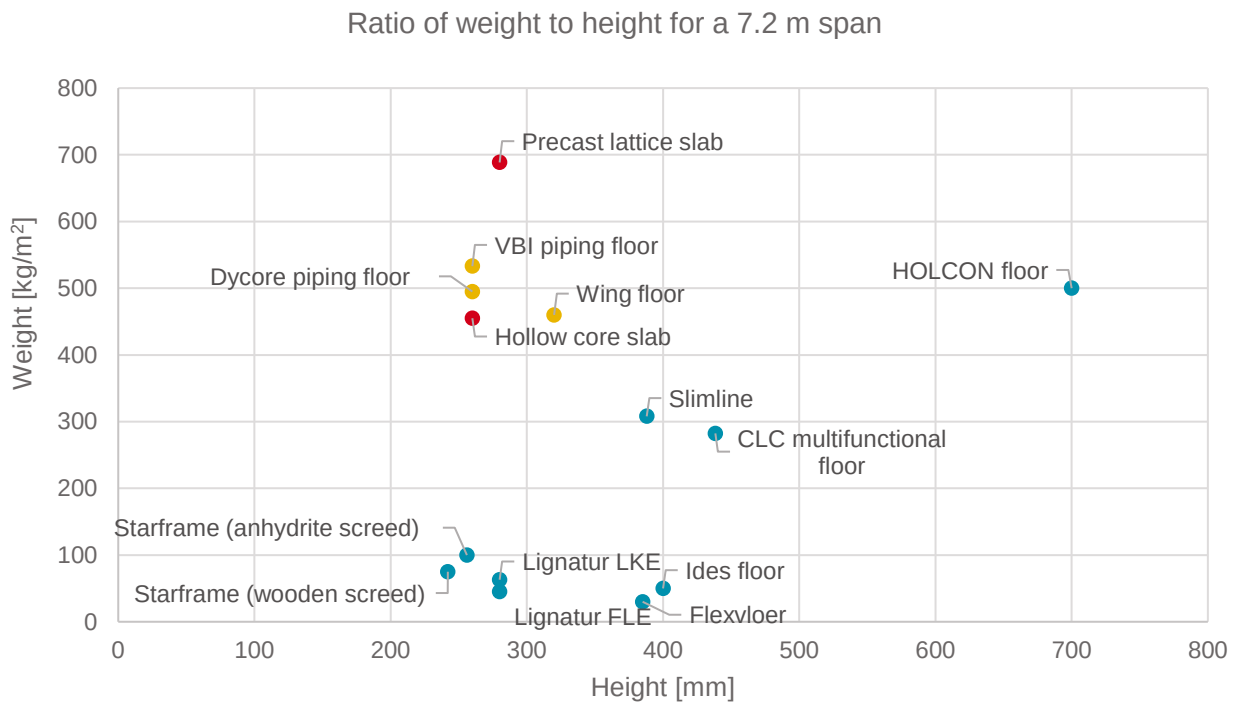


Figure 32: Weight-to-height ratio for a 7.2 m span

The raised floor and suspended ceiling systems are also not included in Figure 32 as these systems do not include the structural floor systems they have to be attached to, hindering a proper comparison. In addition, the weight and the height of both systems are highly variable. The height of raised floor systems ranges from less than 5 cm to up to 2 m and the system weight varies from approximately 25 to 85 kg/m<sup>2</sup> (Lindner Group, n.d.; PBSHolland, n.d.-b; System Floor Technics, n.d.). The minimum void depth of the suspended ceilings is often 100 mm, although it can be lower for some systems (Knauf AMF, 2019; Rockfon, 2013). The panels add another 15 to 25 mm to the total system height (Knauf AMF, 2019). The weight of the suspended ceiling systems ranges from 1 to 14 kg/m<sup>2</sup>, although most systems are in the range of 2.5 to 5 kg/m<sup>2</sup> (Ecophon, n.d.; Rockfon, 2013). The system weight of the raised floor system is considerably higher than that of the suspended ceiling system because the panels need to be load-bearing to support the variable load associated with the use of the space on top. The ceiling panels mainly function as a barrier between the space below and the building services attached to the floor slab above. Of course in both cases, the system height and related weight are highly dependent on the building services that they need to cover up and the relevant acoustics and fire safety requirements.

Based on Figure 32, it can be noted that the height-to-weight ratios of the groove floors, shown in yellow, are similar to that of the regular hollow core slab. The piping floors are slightly heavier and the wing floor has a larger height. Most of the hollow space floors, shown in blue, are lighter than the hollow core slab, with the exception of the HOLCON floor. The HOLCON floor has a standard height for all spans and is therefore not optimized for the span given. The hollow space floors vary greatly in weight. The floors made up of wood or steel components are significantly lighter than the other floor systems. Of these floors, the Lignatur and Starframe concepts are of a similar height to the traditional floor systems, while the Ides floor and the Flexvloer have a larger height. The composite steel-concrete CLC floor system is of a larger height than most other systems, the other composite steel-concrete floor of Slimline is within the same height range as the Ides floor and Flexvloer. Both composite designs weigh less than the traditional floors, but more than the steel and timber floor systems. All floor systems included in Figure 32 are lighter than the precast lattice slab.

### 6.3.1 Flexibility

To answer sub-question 2b, the technical characteristics for flexible design identified in Chapter 5.1 are discussed in relation to the flexible floor systems found.

The design factor of overcapacity is not explicitly mentioned in any of the sources. Most of the designs are optimized to a certain degree, making inherent structural overcapacity unlikely. However, structural overcapacity can often be incorporated by applying a version of the floor element that is higher than required for the design situation at hand. Overcapacity for additional or new building services with other dimensions is present in most hollow floor designs. Although in many cases the space for the routing of the piping is limited in the transversal directions by the size of the openings in the ribs. For the groove model floors, all grooves need to be made during the factory production process. Therefore any overcapacity for the placement of building services needs to be considered beforehand. Generally, the height of both the raised floor systems and the suspended ceiling systems is adaptable, generating a high degree of overcapacity when it comes to the housing of building services. The height of both systems is, however, limited by the requirements for the minimum height of the adjacent spaces.

For the hollow space floors, three different system types can be identified based on material use. The steel designs of the Ides floor and the Starframe floor consist of solely dry connections and are fully demountable. This high level of interface simplicity is not the case for the wooden designs and the designs that combine steel and concrete. For the wooden designs of the Flexvloer and the Liganur floor, glue is used to combine the different components. In case of the combination between steel and concrete, the steel is cast into the concrete. This is done to make the two materials act as one structural element. Although the use of wet connections reduces the demountability of the individual structural elements, it scores positively when it comes to integration because these structural parts are not likely to be adapted separately. The interface simplicity of the floors with grooves is highly dependent on whether mortar is used to fill the grooves up. When mortar is used there is no interface simplicity between the building services and the structural floor. For both the groove model floors and hollow space floors, generally wet joints are used to connect the floor elements. This is typically done to create a diaphragm, but it does reduce the demountability of the floor elements as a whole. The raised floor and suspended ceilings systems consist completely of dry and demountable connections and thus have a high degree of interface simplicity.

The design factor of integration indicates the technical coupling of components that will never be adapted separately. As mentioned, integration is present in the structural combination of the different structural components in the wooden and steel and concrete floor designs. Further integration of elements is not noted in the sources.

The floors with grooves have a certain degree of independence because the building services have their own place within the structure. However, this independence is negated when mortar is used to fill the grooves. Within the hollow space floors, the building services are still part of the floor but are technically separated from its structural function, resulting in a high degree of independence. The building services in the raised floor and suspended ceiling system are fully independent from the load-bearing structure. Not only are the two functions technically separated, they are also spatially separated.

Accessibility is an important aspect of the flexibility of the floor systems. When accessibility is not ensured, the opportunity to utilise the other flexibility factors is greatly reduced. For both the hollow space floors and the floors fitted with grooves, the accessibility of the building services within the floor is dependent on the screed applied. The manufacturers and designers often recommend the use of a removable screed or inspection openings to ensure accessibility. However, this advice is not always put into practice. In reality, due to financial reasons and because of noise insulation requirements, often a screed of cement or anhydrite is applied (Gijsbers, 2011). This fully negates the accessibility of the building services in the floor. For the floors with grooves, the accessibility is not only dependent on the applied screed, but also on whether the grooves are filled with mortar. The building services of the raised floor and suspended ceiling systems remain fully accessible due to the removability of the panels.

Finally, neither durability nor standardisation are explicitly mentioned in the sources. Therefore, the degree to which these characteristics of flexible design are present in the floor systems cannot be discussed in a substantiated manner. However, a certain degree of standardisation can be expected, seeing as virtually all of the floor systems are prefabricated.

### **6.3.2 Advantages and drawbacks**

The advantages and drawbacks of the found floor systems are discussed to answer sub-question 2c. The main advantage of the hollow space floors, the raised floor system, and the suspended ceiling

system is the reconfigurability, allowing for the layout of the building services to be adapted throughout the lifecycle of the floor. Here, the raised floor and suspended ceiling system possess the additional advantage that this flexibility is not dependent on the screed used. Both the hollow space floors and the floors fitted with grooves have the advantage of the building services being integrated within the floor, requiring no additional space on top of or below the floor. The demountability of the steel hollow space systems and the raised floor and suspended ceiling systems is also advantageous when it comes to flexibility and reusability.

Most of the hollow space floor systems have a lower system weight than the traditionally used hollow core slab and precast lattice slab as well as the floors fitted with grooves. This can be seen as an advantage when it comes to total weight to be borne by the rest of the structure and the dimensioning of said structure. On the other hand, a certain mass is required for the acoustic requirements of floor systems.

As mentioned, the flexibility of the floors with integrated building services is highly dependent on the screeds used. This is a drawback of these designs. In addition, the floor elements of these systems are often connected using wet joints, reducing the removability and reusability of the elements. Major drawbacks of the groove model floors are that the location of the grooves needs to be determined ahead of time and that the accessibility of the building services in these grooves is hindered when mortar is used. All of the floor systems found are either of similar height to or of larger height than the commonly used hollow core slab or precast lattice slab. A larger total floor height affects the rest of the building design, resulting for example in a larger façade surface area, different stair configurations, or possibly fewer storeys within existing building height restrictions.

## 6.4 Costs of floor systems

From the interviews in Chapter 5.2, it became apparent that costs play an important role within the building industry. As a result, the costs of a floor design can have a big impact on the likelihood that a floor will be adopted in practice. Therefore, to answer sub-question 3, the costs of the existing floor designs are compared and analysed to see what factors influence the price of a floor system.

### 6.4.1 Cost comparison

The investment costs of a building project are made up out of various components (van Hellenberg Hubar, 2009). For the evaluation of the different floor systems, only the direct building costs are considered. These are the costs that concern the material and equipment use, wages, and subcontracting (Bouwkosten.nl, n.d.; van Hellenberg Hubar, 2009). The direct building costs are directly influenced by the design choices for the building element (E. Koopman, 2020). Other costs are not taken into consideration.



Figure 33: Cost range of existing floor systems

Figure 33 illustrates the cost range for a number of existing floor systems. For the cost range, a span of 5.1 to 6.1 m is assumed. Only a limited number of floor systems are included in this range due to the limited availability of cost information. The costs are given in a range and no exact values are given because the cost information is taken from different sources and no unambiguous information was available (Akse, 2010; Bouwkosten.nl, n.d.; Cobouw, 2020; Houwaard, 2008; van de Kuil, n.d.; van Hellenberg Hubar, 2009; Verlaagdplafondplaatsen, n.d.; Werkspot BV, n.d.). Therefore, the information in Figure 33 is only indicative.

Figure 33 shows that the hollow core slab is the most economical floor system of the designs included in the cost range. The piping floor is a bit higher up in the cost range. As the piping floors are essentially hollow core slabs with grooves for piping, this suggests that the price increase is due to the actions required for the milling of the grooves. The difference between the hollow core slab and piping floor with

the next most economical floor system, the precast lattice slab, is primarily due to an increased use of both reinforcement steel and concrete.

The infra+ floor and the Slimline floor hold the middle ground in the cost range, just above the traditionally used floor systems. Both floor systems have the same material build-up, with a 70 mm concrete slab at the bottom, a steel beam with openings, rubber granulates and a profiled steel sheet on top. These similarities are unsurprising as the Infra+ floor is the precursor to the Slimline floor (Slimline Buildings BV, 2013). In the determination of the costs for both floors, a different steel beam is assumed. For the infra+ floor cost calculation, an IPE300 beam is assumed and for the Slimline floor cost calculation an IPE330 beam is assumed (Akse, 2010; van Hellenberg Hubar, 2009). For the Slimline floor, a smaller IPE beam could be used for application in a residential building for a span of 5.1 to 6.1 m (Slimline Buildings BV, n.d.-a)

For the inclusion in the cost range of Figure 33, the suspended ceiling and raised floor system are both combined with a hollow core slab. Both systems end up on the higher end of the cost range, as they require an additional system in addition to the load-bearing system. The raised floor system is presumably more expensive than the suspended ceiling system because the raised floor systems need to be able to transfer the floor load on top.

On the right-hand side of Figure 33, the HOLCON floor is the least economical system of the floors included. The HOLCON floor has a fixed height for spans of up to 18 m. As a result, this floor design is considerably over-dimensioned for the span considered and additional material is used, driving up the costs of the floor.

Figure 33 also shows that the hollow space floors and the floors with separated building services, shown in blue and green respectively, are within a higher cost range than the traditional floor systems shown in red. When looking at the difference in material use between these floors and the traditional floor systems, as specified for the circularity assessment in Appendix H, it is noticeable that, for example, the Slimline floor does not really require more material than the precast lattice slab. Therefore, it is not likely that the cost increase between these floor systems is due to additional material use. Another difference between both the traditional floor systems and the piping floor with the other flexible floor designs is the combination of elements from different materials. For example the use of concrete slabs and steel beams in the Infra+ floor and the Slimline floor and the use of concrete slabs and a lattice girder for the HOLCON floor. The combination of elements of different materials could be the reason for the cost increase between the floor systems in the lower cost range and the higher cost range. It is possible that this cost increase is related to additional production operations required for the combination of elements from different materials.

Figure 33 does not include the direct building cost information of the timber and steel existing floor designs as no such costs information was available on these floors. A valid cost estimation based on material use alone is also difficult to give, as the prices for both timber and steel are currently spiking (Bouwnieuws, 2021a; Confederatie Bouw, 2021; Noy, 2021). This price spike is illustrated in Figure 34. The main cause for the high timber prices is the recent increase in demand for timber products, in combination with unrest on the international market due to a shift in demand and supply (Bouwnieuws, 2021c). The global COVID-19 pandemic also contributed by reducing the production capacity. The steel prices have doubled since mid-2020, which is a historical record. There was already turmoil in the steel sector before the COVID-19 pandemic due to unrest on the international market and a trade war between economical powers such as the United States, China, Australia, and Russia (Bouwnieuws, 2021b). For both materials, it is not expected that the increased prices and the production delay will be resolved soon (Bouwnieuws, 2021b, 2021c; Confederatie Bouw, 2021).

Generally, timber structures are more expensive to build than concrete structures (Redactie Het Houtblad, 2020; van der Schree, 2021). This is partially due to the inexperience of contractors in working with timber (Redactie Het Houtblad, 2020). It should be noted that this information concerns the entire structure and not just the floor systems. The costs for steel structures in comparison to concrete structures depends on the use case (Evers et al., 2003). No specific information on steel floors in residential buildings was found. Because of the acoustic requirements for floor partitions in residential buildings, a solely steel floor system is not likely to be adequate.



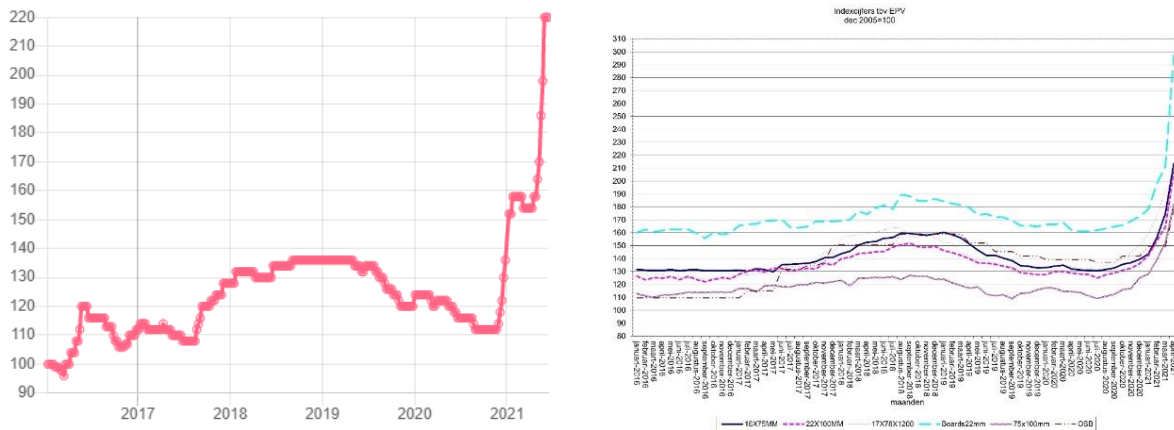


Figure 34: Spiking price index for steel (Van den Brink Staalbouw, 2021) (left) and timber (right) (Centraal Bureau voor de Statistiek, 2021)

## 6.4.2 Cost influencing factors

Based on the cost comparison using Figure 33, it can be said that additional material use causes an increase in cost. This can be seen in the cost difference between the hollow core slab and the precast lattice slab, the infra+ and Slimline floor, and the overall higher costs for the over-dimensioned HOLCON floor. That more material use increases the overall costs of a floor is logical and should be considered in an economical floor design. In the comparison between the hollow core slab and the piping floor, it also becomes clear that the milling of grooves in the floor results in a price increase. From this, it can be concluded that additional operations or labour increase the costs. Finally, it seems that the combination of elements from different materials is also a factor that increases the costs of a floor.

Besides the factors that influence the direct building costs that can be found from the comparison in Figure 33, there are several other ways that floor systems can influence the overall investment costs of a building. For example, the construction time has an effect on the costs of a building project and is not included in the direct building costs used for Figure 33. Floor systems like the precast lattice slab, require propping of the floor during construction and hardening time after the concrete is poured. This results in a longer construction time for the floor itself, as well as delay for other construction activities that need to take place on top of the floor (van Hellenberg Hubar, 2009). The onsite construction time is reduced by using prefabricated floor systems that require no propping.

As was already mentioned in the interviews in Chapter 5.2, the height of a floor system can also influence the overall costs of a building project (Nassar & Al-Qasem, 2020). A higher floor system affects the rest of the structure, requiring for example more façade surface area or different stairway designs, and can reduce the amount of usable surface area within the allotted building height.

## 6.5 Conclusions

Two different types of flexible floor systems exist. Those with the building services integrated within the structural floor height, and those that separate the structural floor from the building services. The former can be further divided into the categories of floors fitted with grooves through which piping can be routed and floors with a hollow space for the placement of building services. The other category consists of raised floor systems and suspended ceiling systems.

When it comes to the flexibility measures incorporated in the flexible floor system designs, accessibility plays a key role. All other indicators of flexibility depend on the degree of accessibility. For both the suspended ceiling and raised floor systems, the accessibility is ensured through the use of removable panels. For the integrated floor systems, the flexibility depends on the type of screed used. The flexibility measure of interface simplicity is mainly present in the demountable steel floor systems. With the suspended ceiling and raised floor systems, the building services and structure are fully independent. For the integrated floor systems, the independence is ensured by providing the building services with their own place within the structure, although this is negated when mortar is used in the grooved floors.



The main advantage of the flexible floor systems is the reconfigurability of the building services within the hollow space floors, the raised floor, and suspended ceiling systems. To ensure reconfigurability in the groove floor systems, additional grooves have to be added during the production process. An important disadvantage of the found floor systems is that most of them have a larger height than the commonly applied floor systems, affecting the rest of the building structure.

The height of the floor systems can influence the costs of the building project. Other cost influencing factors are the time required for construction of the building project and the amount of material used, the additional operations required, and the combination of elements from different materials required for the production of the floor system.

## 7 Assessment methods

To be able to show the effect of flexibility measures on the circularity of floor systems, both the degree of flexibility and circularity of the building component should be made quantifiable and comparable. In line with sub-question 4, a literature study is done to explore the existing assessment methods for flexibility and circularity of building components. The assessment methods found are then evaluated to determine the most relevant methods for the study at hand.

### 7.1 Circularity assessment methods

To determine the effect of flexibility measures on the circularity of a floor system, it is useful to make its degree of circularity comparable through, for example, a score or rating. This way, points of improvement can be identified and the effect of changes in the design on the circularity of the building component can be recognized. Here, circularity should not just be limited to the circularity of the materials used but should encompass the total composition of the building component. The existing assessment methods for the circularity of building components are explored through a literature study. The approach for the literature study can be found in Appendix D.

#### 7.1.1 Results

The circularity of objects or systems can be assessed in different ways. There are tools that evaluate material circularity, such as the Life Cycle Assessment (LCA), the Material Flow Analysis (MFA), and the Environmental Product Declaration (EPD) (Dieckmann et al., 2020; Duurzaam gebouwd, 2019; Wiprächtiger et al., 2020). In the search for a suitable circularity assessment method for this research, the focus was on product circularity, where not only the circularity of the materials used is taken into account but also the composition of the product (Duurzaam gebouwd, 2019). The resulting circularity assessment methods are outlined below.

Dieckmann et al. (2020) developed a method to identify the key barriers to the transition from a linear to a circular economy for end of life products or materials. They have identified nine categories of top-tier barriers that influence this transition. These categories relate to the basic material properties and product characteristics, the availability of suitable processing technology, the environmental impacts associated with current linear management, the organizational context, industry and supply chain issues, external drivers, public perception, the regulatory framework, and the overall economic viability of the transition. The overall scale of these barriers to the transition from a linear to a circular economy is assessed by assigning a level between 0 and 3 to each barrier category, the aggregate score of the material or product can thus range from 0 to 27. The scoring of each barrier category allows specific barriers to be identified as a particular issue. Figure 35 shows a selection of the features of the material characteristics barrier category.

| Material Characteristics that Influence the Linear to Circular Transition                                                                                 | No Potential (Level 0)                                                       | Some Possibility (Level 1)                                            | Good Potential (Level 2)                                                                 | High Potential (Level 3)                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Composition:<br>Is the complexity or heterogeneity of the material expected to stop the transition to circularity?                                        | Highly complex and heterogeneous, Components are very difficult to separate. | Complex composition. However components can be separated with effort. | Simple composition. Composite structure, which can be disassembled at designated joints. | Homogeneous and simple composition. Different components do not need to be separated. |
| Economic value:<br>Is the inherent value of the material likely to stop the transition to circularity?                                                    | No value.                                                                    | Low value.                                                            | Intermediate value.                                                                      | Potential to have high relative value.                                                |
| Components/Parts:<br>Does the material contain many different components that are difficult to separate and will this stop the transition to circularity? | Composite material with many different components.                           | Composite material with limited amount of different components.       | Material has very few components that have potential to be separated.                    | Single material with no impurities or compatible mixed materials.                     |

Figure 35: A selection of the detailed features of material characteristics prohibiting or supporting CE transition (Dieckmann et al., 2020)

Godelet and Schuster (2018) have developed the Circularity Economy Index (CEI) to evaluate the circular economy approach during the early building planning process. The tool supports the evaluation of building materials, components, and assemblies according to the circular economy principles they identified. These principles are renewable raw materials, the absence of pollutants, local origin, circularity, connection of system components, and dismantling. Figure 36 shows the rating of the criterion circularity in five different evaluation levels. All criteria are combined in the assessment matrix, shown in Figure 37, where the six criteria are considered at the three different building levels to come to an overall rating for the building element. All criteria are weighted equally and the index is awarded as a percentage. The evaluation of the CEI is done using a simple Excel sheet. The results are shown in a spider network diagram, as shown in Figure 38, to show at a glance to which extend the building component corresponds with the circular economy approach. Unfortunately, said Excel sheet was not uncovered in the literature study.

| # | Material                                                         | Rating |
|---|------------------------------------------------------------------|--------|
| 4 | Circularity                                                      |        |
|   | Building material can be reused without any effort. Upcycling.   | 100 %  |
|   | Building material can be recycled with effort.                   | 75 %   |
|   | Building material can be recycled at great expense. Downcycling. | 50 %   |
|   | Thermal recovery.                                                | 25 %   |
|   | Deposting.                                                       | 0 %    |

Figure 36: Scoring system, criterion "circularity" (Godelet & Schuster, 2018)

| Criteria          | Material selection   |                       |              |             | Construction           |              |
|-------------------|----------------------|-----------------------|--------------|-------------|------------------------|--------------|
|                   | Renew. raw materials | Absence of pollutants | Local origin | Circularity | Structural connections | Dis-mantling |
| Building outlines |                      |                       |              |             |                        |              |
| Materials 'm'     |                      |                       |              |             |                        |              |
| m 001             | ... %                | ... %                 | ... %        | ... %       |                        |              |
| m ...             | ... %                | ... %                 | ... %        | ... %       |                        |              |
| Components 'c'    |                      |                       |              |             |                        |              |
| c 001             | ... %                | ... %                 | ... %        | ... %       | ... %                  | ... %        |
| c ...             | ... %                | ... %                 | ... %        | ... %       | ... %                  | ... %        |
| Assembly 'a'      |                      |                       |              |             |                        |              |
| a 001             | ... %                | ... %                 | ... %        | ... %       | ... %                  | ... %        |
| a ...             | ... %                | ... %                 | ... %        | ... %       | ... %                  | ... %        |

Figure 37: Overview of the Circular Economy Index matrix (Godelet & Schuster, 2018)

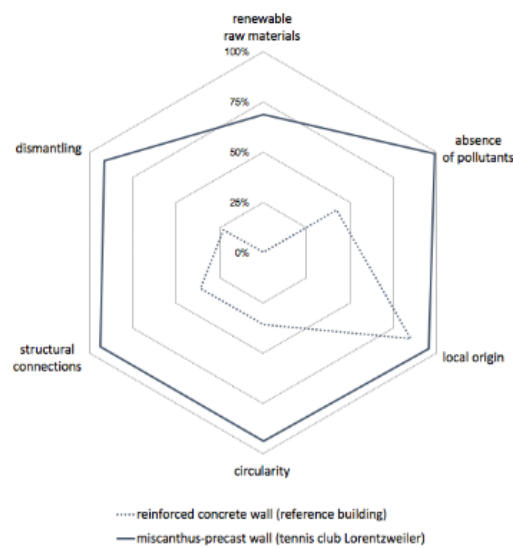


Figure 38: The "spider network diagram "comparing a miscanthus-precast wall with a concrete wall (Godelet & Schuster, 2018)

Griffiths and Cayzer (2016) extended the Kingfisher Circularity Calculator (KCC) into their Circular Economy Indicator Prototype (CEIP). Through interviews, they identified fifteen possible variables which could be linked to the Ellen MacArthur Foundation circular economy principles. The CEIP was designed by defining a question in correspondence to each of these variables, taking or amending these from the KCC where appropriate. These questions are grouped per lifecycle stage. A single aggregate score shows the circularity of the product. The CEIP was designed to be used in Excel. Figure 39 shows a part of the CEIP Excel interface. Unfortunately, not all questions of the CEIP are part of the literature and the CEIP Excel sheet was not uncovered in the literature study.

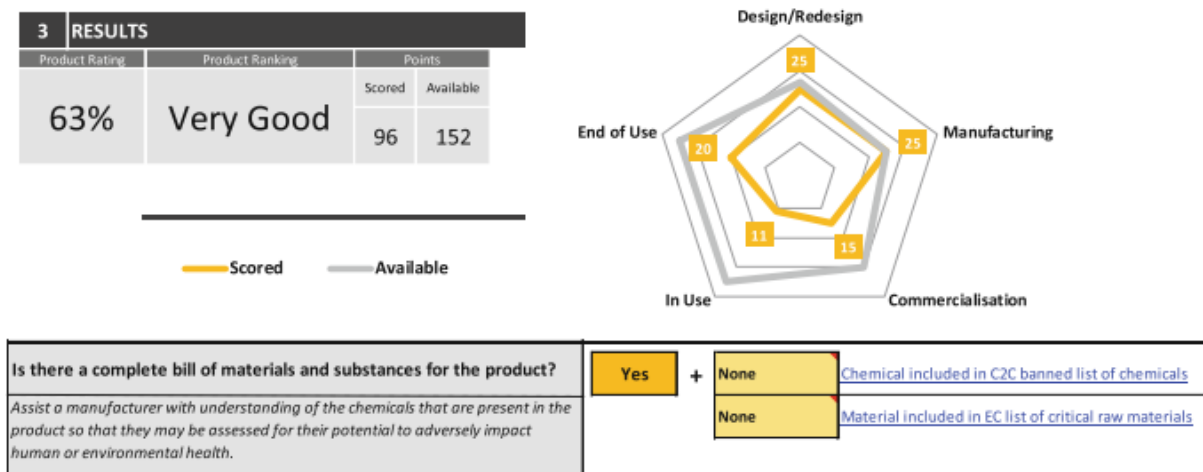


Figure 39: Selected part of the CEIP interface (Griffiths & Cayzer, 2016)

Verberne (2016) developed the Building Circularity Indicator (BCI), which is made up out of the System Circularity Indicator (SCI), Product Circularity Indicator (PCI), and Material Circularity Indicator (MCI). The method is based on Key Performance Indicators related to the Ellen MacArthur Foundation principles for circularity. Figure 40 shows the structure of the assessment method. Applying the assessment method, first, the MCI is quantified for each product within the building. Hereby, the material input and output and the utility of the product are evaluated. Next, the MCI for each product is weighted by multiplying it by seven disassembly factors, resulting in the PCI. Each factor consists of a weight between 0 and 1, where 0 represents the worst case for reapplication and 1 represents the best reapplication potential (Cottafava & Ritzen, 2020). Third, the SCI is calculated by weighting the PCI of each product by its mass and separation of systems based on Brand's six building layers (Cottafava &

Ritzen, 2020; Verberne, 2016). Finally, the BCI is assessed by applying a factor for the level of importance for each system (Verberne, 2016).

Although originally developed by Verberne (2016), multiple versions of the BCI assessment method exist. Van Vliet (2018) revised Verberne's method by adapting the disassembly factors and leaving out the weight normalization. Alba Concepts elaborated on the work by Verberne and Van Vliet and developed a version of BCI based on the three levels of a Product Circularity Index (PCI), an Element Circularity Index (ECI) and a Building Circularity Index, which Van Schaik (2019) modified for his application to building foundations. Cottafava and Ritzen (2020) developed the Predictive BCI (PBCI) to assess the potential for recycling, remanufacturing, reuse, or repair and consequently the potential unrecoverable waste percentage. This is done by applying the disassembly factors directly inside the MCI computation.

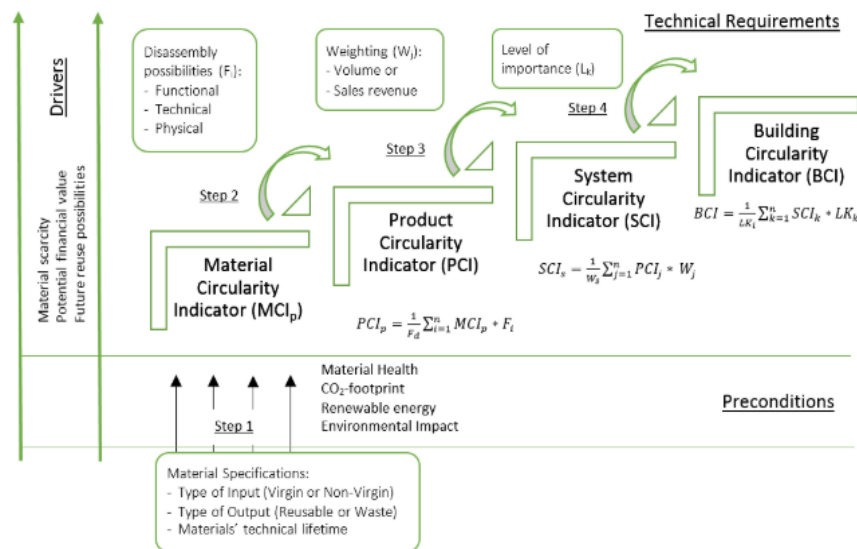


Figure 40: Conceptual structure for the BCI assessment model (Verberne, 2016)

Platform CB'23 (2020) is in the process of developing a measuring method for circularity in the construction industry. The method measures the impact of construction projects on three circularity goals. These goals are protecting existing resources, protecting the environment, and protecting existing value. For each goal, core indicators are identified on which the project or product can be scored. The method is applicable in every part of the construction process and can also measure the expected degree of circularity. Besides the core indicators, a report on adaptability is part of the method. The report should illustrate qualitatively how adaptivity is considered in the design. There are plans to include adaptability in the core indicators for future versions of the method. Currently, the calculation methods for some of the indicators are still being developed. Upcoming versions of the method should also include the weighting of results and a combined overall score. Figure 41 gives an indication of what the interface of the Platform CB'23 method could look like.

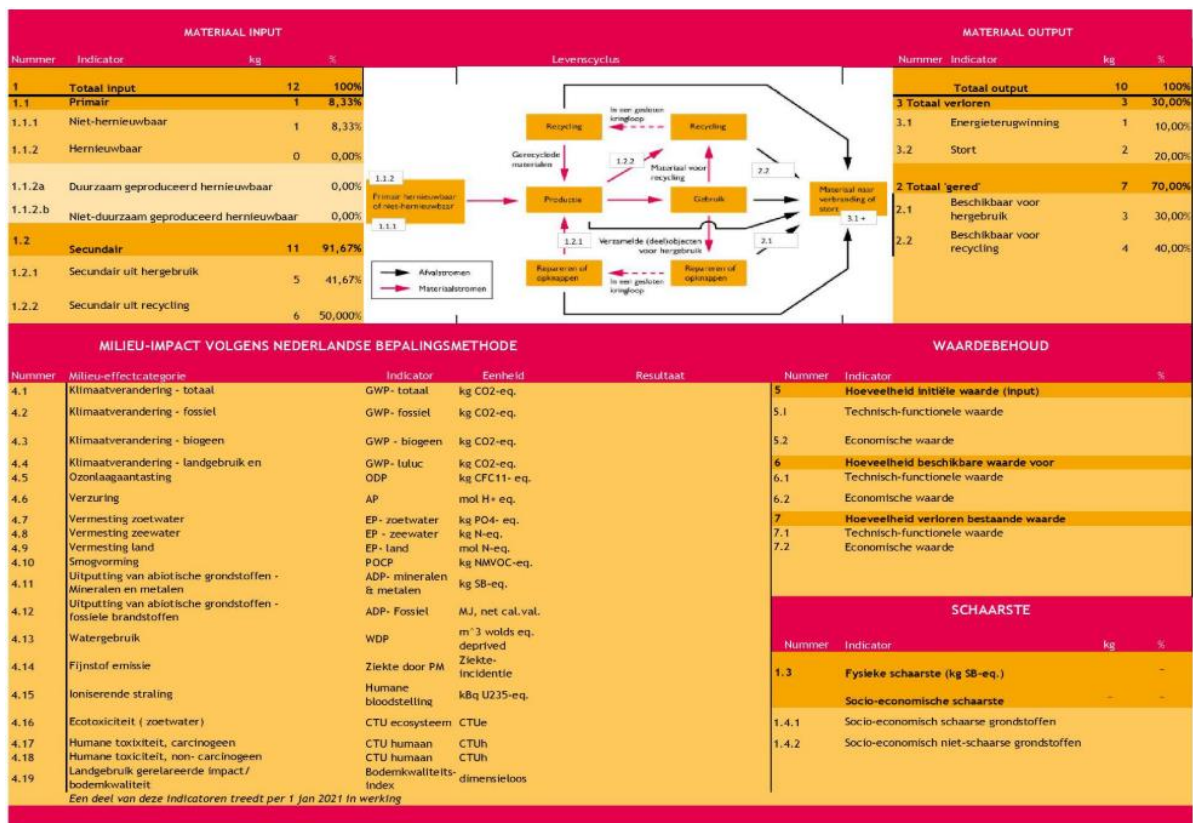


Figure 41: Example of a communication format for the results of the Platform CB'23 measuring method (Platform CB'23, 2020)

## 7.1.2 Discussion

The assessment methods by Dieckmann et al. (2020) and Griffiths and Cayzer (2016) are not specifically intended to assess building structures. The barrier based assessment method by Dieckmann et al. is designed to be applied in different types of industries and could thus also be used for the building industry. Griffiths and Cayzer specifically address that the variables used in their CEIP method were designed for products in the Home Improvement sector and that it should not be assumed that CEIP is reliable for products from other industries. The other circularity assessment methods are all designed to be used within the building industry.

Unfortunately, the full assessment method described in the sources could not be found in all cases. This is the case for the barrier based assessment method, the Circular Economy Index, and the Circular Economy Indicator Prototype. Because the full methods are not available, they cannot be applied in this research. The current version of the Platform CB'23 method is fully accessible, however since some of the calculation methods are not developed yet, this method will also not be applied in this research. This method could have been very useful if it had already been fully developed. Especially with the inclusion of the adaptability indicators, it perhaps could have served as the flexibility assessment method as well.

The Building Circularity Indicator is designed to be applied to buildings and all weights and formulas needed are available in the literature. It also includes both the materials used and the composition of products in its circularity assessment. This method is, therefore, suitable to be used in this research. For this research, however, it is not necessary to assess an entire building. Therefore the Building Circularity Indicator method could be applied up to the product or assembly level.

## 7.2 Flexibility assessment methods

To be able to show the effect of design changes on the flexibility of a floor system or to identify possible points of improvement, it is useful to be able to quantify the degree of flexibility. The existing flexibility or adaptability assessment methods are explored through a literature study. The approach for the literature study can be found in Appendix E.



### 7.2.1 Results

Through the literature study, several different assessment methods for flexibility in the building industry were found. The assessment methods vary in their scale, focal points, indicators included, and type of end result. All of the flexibility assessment methods found are outlined below.

Geldermans et al. (2019b) established the Circ-Flex assessment guidelines in order to provide a more integrated and inclusive approach to the transition from a linear to a circular built environment. The system combines circular and flexible characteristics. The circular characteristics concern processes, materials and stakeholders that accommodate a circular flow of building materials and products. The flexible characteristics concern design that allows for easy rearrangement of infill components and accommodation of changing needs of occupants. These characteristics are coupled to issues of end-user health and well-being with as a result the Circ-Flex guidelines as shown in Figure 42.

| Category                       | Summary of Criteria                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Material Health & Transparency | X-listed chemicals in raw materials/product or process, following the Cradle to Cradle ®Certification Standard; Complete characterization of applied (raw) materials; Materials defined as biological or technological ingredients; Short term and long term emission control regarding potentially damaging offset of chemicals; Protective practices in repair/maintenance/disposal, linked to hazardous materials. |
| Material Reutilization         | Defined appropriate cycle/reutilization route (biological or technological); Designed for the cycle, following a reutilization score expressed in percentages of recycled content, rapidly renewable content, recyclable content, and/or biodegradable content; Management strategy for logistics and recovery pathways; Collection and reutilization program.                                                        |
| Mould control                  | Anticipation of (delayed) moisture related issues, in relation to operational conditions.                                                                                                                                                                                                                                                                                                                             |
| Health & Wellbeing Awareness   | Provision of information and guidelines throughout the whole value network, highlighting the relationship between health & well-being and buildings/building components.                                                                                                                                                                                                                                              |
| Integrative Design             | Facilitation of stakeholder co-creation towards continuous improvement.                                                                                                                                                                                                                                                                                                                                               |
| Perceived Performance          | Short and long-term performance-evaluations relating the component's functioning. Primarily aimed at the use stage but also anticipating construction and disposal.                                                                                                                                                                                                                                                   |

Figure 42: Circ-Flex assessment guidelines (Geldermans et al., 2019b)

Flex 4.0 is the most recent version of a method developed to assess the adaptive capacity of buildings (Geraedts, 2016). It is a practical assessment instrument based on 44 flexibility key performance indicators and associated assessment values. The indicators form the basic framework for the Flex 4.0 method and have been divided into two categories. The first category consists of 12 flexibility performance indicators and is called the support category. This category contains the flexibility performance indicators that can be generally applied, independent of the type of real estate to be addressed. The second category is the infill category, which consists of 32 flexibility indicators that are specifically applicable for a certain type of real estate. Each flexibility performance indicator is assigned a value from 1 to 4, where a higher score is a better score. The criteria to assign a specific score is described in the assessment values. To use Flex 4.0 in practice, assessment forms have been developed that incorporate default weighting factors, as shown in Figure 43.



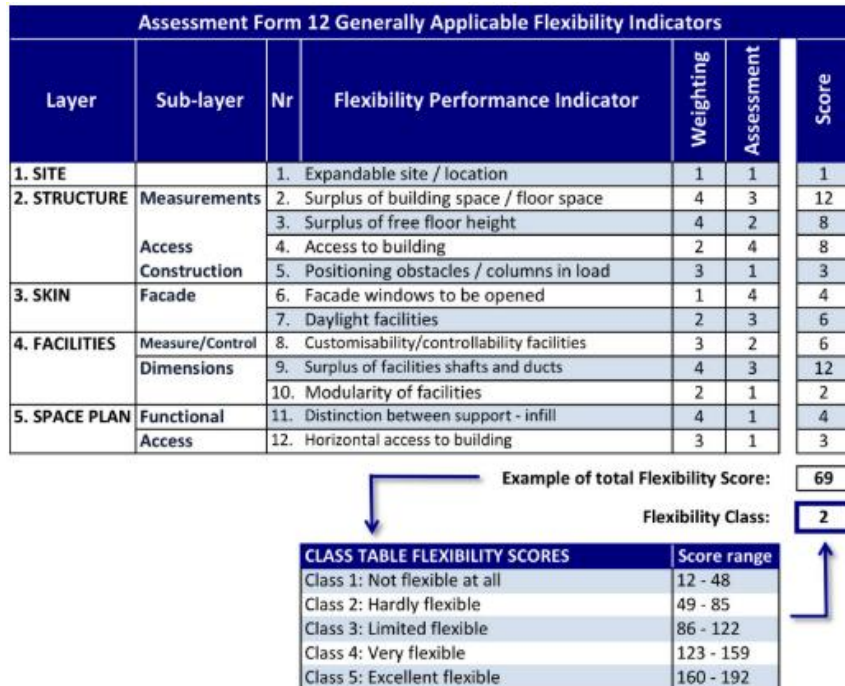


Figure 43: Example of a fictive assessment of a building with the 12 generally applicable flexibility indicators (Geraedts, 2016)

Geraedts (1996) developed Flexis as a method to facilitate communication about and assessment of the flexibility between office buildings and their building services. The flexibility of the building services is addressed on the aspects of divisibility, adaptability, expandability, and multifunctionality. The flexibility assessment is determined using an ascending flexibility scale from 1 to 5 on each of these aspects. To determine the score, flexibility criteria and corresponding weights are used. Finally, a flexibility profile of the building services systems is produced, an example of which is shown in Figure 44.

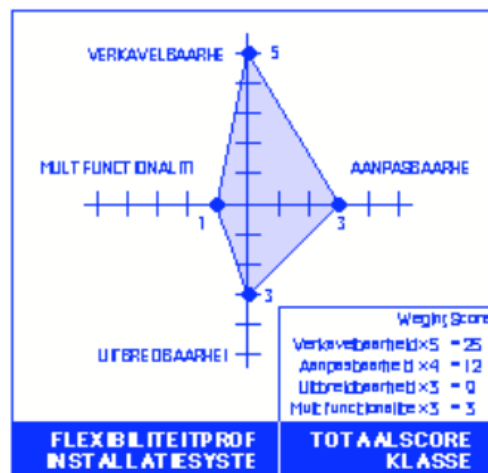


Figure 44: Example Flexis flexibility profile (Geraedts, 1996)

The Comparative Selection method for Adaptability measures (CSA method) by Gijsbers and Lichtenberg (2012) was designed to impartially select and compare a number of adaptability measures based on expected scenarios of future changing user demands. Using the method, first, a number of adaptability measures are selected and developed based on a scenario of future user requirements. Subsequently, the degree of efficiency of the chosen measures is assessed by quantifying the required effort for an adaptation (in man-hours  $\times$  nuisance), costs, and environmental costs. Each category is evaluated separately, without an overall score as the units are not compatible and different stakeholders have different priorities. The CSA method is limited to functional demands arising from expected changes

in the user demands. Figure 45 gives an example of a comparison of different adaptability solutions using the CSA method.

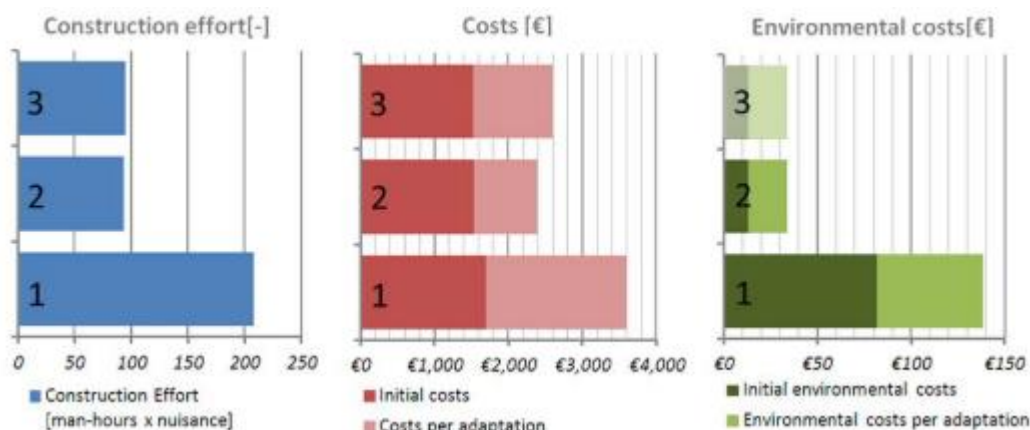


Figure 45: Example of results of the quantification of the efficiency of the adaptability solution in the CSA method (Gijssbers & Lichtenberg, 2012)

Hermans et al. (2014) developed an assessment method to enable owners or investors of real estate to assess the future value of buildings from the perspective of adaptability. The method guides the user through questions and focus points to determine the future value of the buildings. The assessment of the design is done through three tests. First, requirements need to be formulated in order to address whether the design is sufficiently adaptable. Figure 46 gives an example of the comparison between requirements on the left and design characteristics on the right. To assess the adaptability, each indicator, divided into the categories of reconfigurability, expandability and rejectability, is assigned a measurement unit which can be scored on a scale of 1 to 4. In addition to the adaptability test, the financial-economical and the sustainability value of the design is determined.

| Prestatie-eisen gebruiker door eigenaar | WEGING | EISENNIVEAU (VRAAG) |                        |               |               |               | PRESTATIES (AANBOD) |                          |               |               |               | Beoordeling |    |     |     |
|-----------------------------------------|--------|---------------------|------------------------|---------------|---------------|---------------|---------------------|--------------------------|---------------|---------------|---------------|-------------|----|-----|-----|
|                                         |        | Specifiek           | Gewenste gewogen score |               |               |               | Specifiek           | Werkelijke gewogen score |               |               |               |             |    |     |     |
|                                         |        |                     | LAAG                   | Score 1 tot 2 | Score 2 tot 3 | Score 3 tot 4 |                     | HOOG                     | LAAG          | Score 2 tot 3 | Score 3 tot 4 | HOOG        |    |     |     |
|                                         |        |                     | Score 1 tot 2          |               |               |               |                     | Score 4                  | Score 1 tot 2 |               |               | Score 4     |    |     |     |
| Herindelingsflexibiliteit               |        |                     |                        |               |               |               |                     |                          |               |               |               |             |    |     |     |
| G 1 Herindeelbaar                       | 40%    |                     |                        |               |               |               |                     |                          |               |               |               | -           | 0  | 0   |     |
| G 2 Verplaatsen Intern                  | 0%     |                     |                        |               |               |               |                     |                          |               |               |               | +           | 10 | 0   |     |
| G 3 Relatie Intern                      | 0%     |                     |                        |               |               |               |                     |                          |               |               |               | 0           | 5  | 0   |     |
| G 4 Kwaliteit                           | 20%    |                     |                        |               |               |               |                     |                          |               |               |               | 0           | 5  | 1   |     |
| G 5 Voorzieningen                       | 10%    |                     |                        |               |               |               |                     |                          |               |               |               | 0           | 5  | 0,5 |     |
| Uitbreidingsflexibiliteit               |        |                     |                        |               |               |               |                     |                          |               |               |               |             |    |     |     |
| G 6 Uitbreidbaar                        | 20%    |                     |                        |               |               |               |                     |                          |               |               |               | +           | 10 | 2   |     |
| Afstotingsflexibiliteit                 |        |                     |                        |               |               |               |                     |                          |               |               |               |             |    |     |     |
| G 7 Afstootbaar                         | 10%    |                     |                        |               |               |               |                     |                          |               |               |               | +           | 10 | 1   |     |
|                                         | 100%   |                     |                        |               |               |               |                     |                          |               |               |               |             |    |     | 4,5 |

Figure 46: Example comparisons between adaptability requirements and adaptability performance (Hermans et al., 2014)

Andrade and Bragança (2019) developed a simple method to allow designers to compare and evaluate the flexibility and adaptability of different design solutions. The indicators consist of two sub-indicators “flexibility provision” and “adaptability capacity”. The flexibility provision evaluates the design strategies adopted to accommodate change, promote future-proof homes, and ease of disassembly. It is assessed by using a simplification of the Transformation Capacity (TC) method by Durmisevic (2006). The TC method was simplified to ease its use during the early design stages. Fewer input levels are used and the aggregation method is simplified. The adaptability capacity quantifies the available adaptable space. This is calculated by taking the difference between the net internal area and the internal fixed area.

As mentioned, Andrade and Bragança based their flexibility provision indicator on the TC method by Durmisevic (2006). They also suggest using Durmisevic’s full method during the later design stages when more information is available. Durmisevic developed the method to assess the transformation capacity of building structures based on their disassembly potential. The model is based on eight aspects of deconstruction and their sub-aspects. The model distinguishes between three design domains of

configuration: material, technical, and physical decomposition. Figure 47 shows the hierarchical structure of the model. The first level is the input level and consists of sub-components and a specification of their impact on the main aspects. The second level represents the effect of the main aspect on the material levels, hierarchy, and interface of the building configuration. Weights define the hierarchy of importance of each aspect. At the third level, the impact of the components of the building configuration on the indicators of transformation is specified. These indicators of transformation are determined by Durmisevic to be independence and exchangeability. Finally, at the fourth level, the impact of the indicators of transformation on the disassembly potential of the building is determined. As a result, the building structure can be grouped into one of three categories, where category 1 has a high transformation capacity and category 3 has a low transformation capacity. The assessment of each disassembly factor can be represented in a radial diagram, as illustrated in Figure 48.

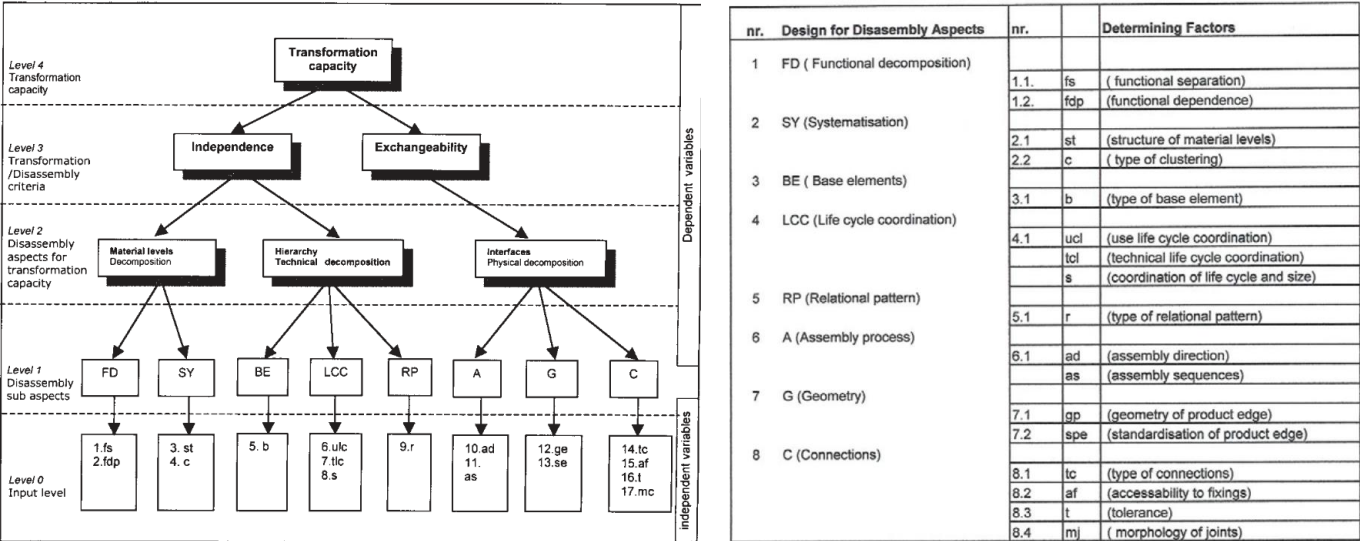


Figure 47: Hierarchical structure and list of design for disassembly aspects for the transformation capacity model (Durmisevic, 2006)

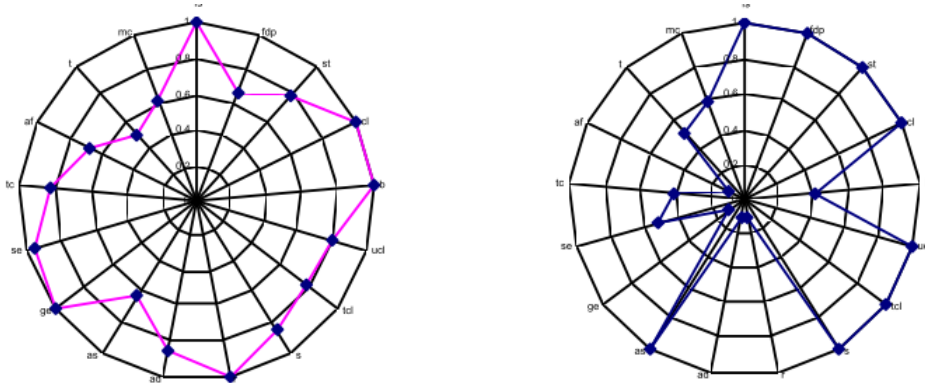


Figure 48: Example of a radial diagram for the transformation capacity of an object (Durmisevic, 2006)

Koopman (2010) developed a matrix model that assesses the flexibility of a structure based on the capacity of the structure to enable changes to be made to other layers of the building. The layers considered are the skin, access, services, scenery, and space. Six different indicators are used to assess the interaction of the structure with the other building layers. These indicators are integration, coupling, accessibility, capacity, dimension, and obstruction. Through a survey, Koopman determined the importance of different configurations, as shown by the darker cells of the matrix model in Figure 49. Krijntjes (2016) adapted the matrix model in order to find a better correlation between how a building scored using the method and the actual life span of the building. This was done by reducing the number of configurations and adding the indicator effort to the model.

|                     | 1. Gebouwschil |        | 2. Ontsluiting |            | 3. Installaties       |                  |                         |                     | 4. Encensering |                                     | 5. Ruimte |
|---------------------|----------------|--------|----------------|------------|-----------------------|------------------|-------------------------|---------------------|----------------|-------------------------------------|-----------|
|                     | A1 wand        | A2 dak | B1 C-roofen    | B2 vloeren | Opwekking en afgifte  |                  | Distributie             |                     | C1 afwerking   | C2 niet afgewerkte vloeren/plafonds |           |
|                     |                |        |                |            | A3 verwarmingsaanvoer | A4 afvoersysteem | B3 verwarmingsleidingen | B4 afvoersleidingen |                |                                     |           |
| A. Integratie       | 5,5            | 0,0    | 1,0            | 1,0        | 3,0                   | 2,0              | 9,5                     | 4,5                 | 2,0            |                                     | 1,5       |
| B. Koppeling        | 15,5           | 0,0    | 1,0            | 0,0        | 2,0                   | 4,0              | 7,0                     | 5,0                 | 5,0            | 7,5                                 | 2,5       |
| C. Toegankelijkheid | 2,0            | 1,0    | 6,0            | 5,0        | 2,0                   | 1,0              | 4,5                     | 5,5                 |                |                                     |           |
| D. Draagcapaciteit  | 3,0            | 5,0    | 1,0            | 1,0        | 0,0                   | 0,0              | 0,0                     | 0,0                 | 0,0            | 4,0                                 | 10,0      |
| E. Meet             |                |        | 1,0            | 1,0        | 1,0                   | 1,0              | 2,0                     | 1,0                 | 2,0            | 2,0                                 | 15,0      |
| F. Obstructie       | 1,5            | 1,5    | 0,0            | 3,5        |                       |                  | 4,5                     | 1,0                 |                |                                     | 9,0       |

Figure 49: Configuration of functional building layers and indicators with their importance (E. F. Koopman, 2010)

## 7.2.2 Discussion

Many of the flexibility assessment methods found are designed to be used at a full building scale rather than at the building component level. Because of this, some of them include categories or indicators that are not directly relevant at a building component level. The Flex 4.0 method by Geraedts (2016) and the matrix model by Koopman (2010) or Krijntjes (2016) include other building layers such as the skin, site and scenery which are not directly related to the assessment of a specific building component. The indicators at the structure and facilities level are more general and therefore less suitable for the focussed assessment of building components. The future value assessment method by Hermans et al. (2014) is also intended to assess full buildings and is therefore set up too broadly to be applicable at a building component level. On the opposite spectrum, the Flexis assessment method (Geraedts, 1996) is focused only on the building services aspect of flexibility. As the aim of this research is to look into the combination of building services and the structural function of the floor, the focus of the Flexis method is too narrow.

Different assessment methods use different approaches or metrics to score flexibility. Most of them score the different indicators on a scale. These scores are combined to form an overall verdict, while the individual scores can be used to pinpoint outliers and possible points of improvement. The Circ-Flex assessment guidelines (Geldermans et al., 2019a) are guidelines and therefore do not use an index to indicate the degree of circularity and flexibility. This makes it harder to effectively compare different design options. In addition, the Circ-Flex assessment guidelines include categories that do not match with the focus of the research at hand. The CSA method developed by Gijsbers and Lichtenberg (2012) scores its three categories separately, using separate units of measurement. The use of these measurement units requires more information and expertise than the scoring on a scale as used in the other assessment methods. Aside from the complexity of the assessment units, the aim of the CSA method is to assess the efficiency of different adaptability measures rather than the degree of adaptability or flexibility, causing the method to be less applicable within the scope of this research.

The assessment method by Andrade and Bragança (2019) consists of two sub-indicators. The adaptability capacity indicator regards spatial flexibility and is therefore not directly applicable for the research at hand. The flexibility provision indicator uses a simplification of the Transformation Capacity method by Durmisevic (2006). As Andrade and Bragança use fewer input levels, a more complete picture of the flexibility can be painted using the full TC method by Durmisevic. It should be noted that the TC method assesses the transformation capacity of building structures based on their disassembly potential. Even though there is overlap between design for disassembly and design for flexibility, these are two different design strategies. Therefore, a comparison was made between the design for disassembly aspects used in the TC assessment method and the flexible design factors identified in Chapter 5.1.

Figure 50 show the connections that can be made between the design for disassembly aspects used in the TC method and the technical characteristics of flexibility identified in Chapter 5.1. Most of the technical characteristics of flexibility can be matched with the design for disassembly aspects. Especially the flexibility characteristics of independence and integration are well connected, also interface simplicity is adequately represented. These three characteristics seem to form the biggest overlap between the flexibility characteristics and the design for disassembly aspects. The connections with both standardisation and accessibility are shown as a dashed arrow because the connection is only partial. Standardisation of the geometry of the product edge benefits disassembly and with regard to the connections, Durmisevic mentions the importance of the accessibility of the fixings for disassembly. In



both cases, the design for disassembly aspect is related to the flexibility characteristic but does not cover their full extent. The aspect of relational pattern has to do with the way components relate to each other and whether the substitution of one element has considerable consequences on related parts and their connection. This aspect is closely related to the flexible design factor of removability. Removability requires the flexibility characteristics of overcapacity, interface simplicity, independence, and accessibility. These connections are shown using a dotted line. The characteristic of durability is not represented at all in the design for disassembly aspects. It can be concluded that the focal point of the TC method is different from flexibility. While some flexibility characteristics are well represented, others are not or only partially or indirectly represented and are thus not sufficiently addressed for a proper assessment of flexibility.

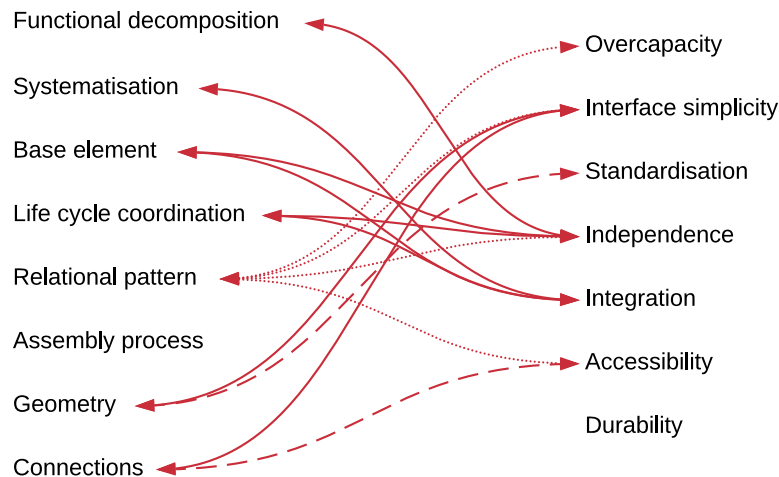


Figure 50: Relations between the TC design for disassembly aspects and the technical characteristics of flexibility

### 7.2.3 Flexibility assessment method based on the technical characteristics of flexibility

As no suitable flexibility assessment method was found, other options to gauge the flexibility of floor design are explored. The first option considered is the adaptation of the disassembly factors for the BCI assessment method to include flexibility. This way the circularity and flexibility of the floor designs could be assessed using a single assessment method.

The adaptation of the disassembly factors could be done based on the technical characteristics of flexible design identified in Chapter 5.1. The adaptation would include the addition of some factors that are not represented in the current disassembly factors, such as overcapacity and durability, as well as the change of some disassembly factors to include a wider range of characteristics. An example of the latter is the disassembly factor 'accessibility to fixings and intermediary' in Verbernes (2016) version of the BCI and 'accessibility to connections' or 'connection accessibility' in later versions (Cottafava & Ritzen, 2020; Van Vliet, 2018). This disassembly factor would be changed to include not only accessibility to connections, but also to different systems within an element, such as the building services within a floor. The adaptation of the BCI disassembly factors could also include the removal or bundling of some of the factors, as some of the flexibility characteristics are more frequently represented in the disassembly factors than others. This is for example the case for the characteristics of interface simplicity and independence, both of which are critical for the disassembly potential of a structure.

There are a couple of things that need to be addressed when considering the adaptation of the existing BCI assessment method. First of all, to what degree do the changes to the disassembly factors distort the final circularity score? The method is not designed or validated for the inclusion of flexibility, therefore it is unclear whether the adapted BCI method would still give an accurate measurement of the circularity of the design. The flexibility characteristic of overcapacity could even be in contrast with the circularity principles. For circularity, reduction of (virgin) material use is a core value, whereas for overcapacity additional material is typically used in anticipation of future changes in requirements. Due to this contrast, the inclusion of the overcapacity characteristic in the BCI disassembly factors is complicated. In addition, if the flexibility is included in the disassembly factors, there is no distinguished flexibility score. The degree of flexibility is then combined with the degree of disassembly potential within the circularity score.



This makes it difficult to evaluate the flexibility of a design, pinpoint the areas of improvement for flexibility, or show the improved flexibility between designs. It also makes it harder to distinguish the effect of flexibility measurements on the circularity of a design. For these reasons, it is decided to not use an adapted version of the BCI as the flexibility assessment method.

Instead of using an adapted version of the BCI to assess the flexibility of designs, a new flexibility assessment method is devised based on the technical characteristics of flexibility as identified in Chapter 5.1. To assess the design of a building component, each characteristic is scored on a scale of 0 to 4. These scores are combined to give an indication of the overall flexibility of the design. The individual scores for the characteristics can be used to evaluate areas of improvement. The rationale behind the weights and scoring of each characteristic of flexibility is explained in the following paragraphs.

### 7.2.3.1 Weights

Weights are applied to the different characteristics of flexibility to establish their relative importance (Brown, 2007). There are many different ways to derive weights, varying in complexity, the chance of bias, and resource requirements (Németh et al., 2019). Here, the weights are determined using the method proposed by Song and Kang (2016). This method is an adaptation of the widely applied Analytical Hierarchy Process (AHP). The method applies the hierarchy structure and the pairwise comparison from the AHP method but complements the disadvantages of AHP by maintaining consistency and reducing the number of comparisons, resulting in a comprehensive and systematic method that can be readily applied due to its simplicity in procedure and formulas (Song & Kang, 2016). The steps taken to determine the weights can be found in Appendix F, the final weights are given in Table 19.

Table 19: Flexibility assessment method weights

| Characteristic of flexibility | Weight |
|-------------------------------|--------|
| Accessibility                 | 0.186  |
| Durability                    | 0.119  |
| Independence                  | 0.146  |
| Integration                   | 0.093  |
| Interface simplicity          | 0.160  |
| Overcapacity                  | 0.167  |
| Standardisation               | 0.130  |

### 7.2.3.2 Accessibility

The scoring of the accessibility characteristic is inspired by the scoring of the ‘accessibility to connection’ disassembly factor by Van Vliet (2018). The score is determined based on the effort and damage required to access different parts of the building element. The lifting of a panel is an example of accessibility without any operation. Non-damaging operations include the removal of screws or other fasteners. An example of repairable damage is the milling cutting of an opening that can be patched aesthetically. A damaging operation requires substantial fixing, here a distinction is made between damaging operations that do not impact the essential functioning of the building element and those that do.

Table 20: Scoring of the accessibility characteristic of flexibility

|                      |                                                                    |          |
|----------------------|--------------------------------------------------------------------|----------|
| <b>Accessibility</b> | Accessible without any operation                                   | <b>4</b> |
|                      | Accessible through non-damaging operation                          | <b>3</b> |
|                      | Accessible through operation resulting in repairable damage        | <b>2</b> |
|                      | Accessible through damaging operation, not affecting functionality | <b>1</b> |
|                      | Not accessible                                                     | <b>0</b> |

### 7.2.3.3 Durability

The durability characteristic is scored based on the design life and the associated required maintenance to achieve this design life. The minimum design life is set at 50 years, based on the design life for buildings required in the Eurocode (Nederlands Normalisatie-instituut, 2019c).

Table 21: Scoring of the durability characteristic of flexibility

|                   |                                                                                         |          |
|-------------------|-----------------------------------------------------------------------------------------|----------|
| <b>Durability</b> | High design life ( $\geq 100$ years), requiring a modest level of maintenance           | <b>4</b> |
|                   | Intermediate design life ( $\geq 75$ years), requiring a modest level of maintenance    | <b>3</b> |
|                   | Minimum design life ( $\geq 50$ years), requiring a modest level of maintenance         | <b>2</b> |
|                   | Minimum design life ( $\geq 50$ years), requiring a medium to high level of maintenance | <b>1</b> |
|                   | Below minimum design life ( $\leq 50$ years)                                            | <b>0</b> |

### 7.2.3.4 Independence

Independence is scored based on the degree of zoning and the interconnectedness of these zones. Zoning regards the degree to which elements of a specific function have their own space within the building system. The extent to which these zones are adjoined or intertwined is addressed through the interconnections.

Table 22: Scoring of the independence characteristic of flexibility

|                     |                                                       |          |
|---------------------|-------------------------------------------------------|----------|
| <b>Independence</b> | Full separation of functions, no interconnections     | <b>4</b> |
|                     | Zoning of functions, few intentional interconnections | <b>3</b> |
|                     | Zoning of functions, partial interconnection          | <b>2</b> |
|                     | Interconnected zoning of functions                    | <b>1</b> |
|                     | No zoning, fully combined                             | <b>0</b> |

### 7.2.3.5 Integration

For the scoring of the integration characteristic, it is assessed to what extent all components that are not reasonable expected to be adapted separately are integrated into separate elements. Components are part of a separate system or are not reasonable expected to be adapted separately when they have a corresponding service life and function. At the highest score, when full integration is achieved, complete systems of the same function and service life are integrated into one element that can easily be moved or removed from the overall system.

Table 23: Scoring of the integration characteristic of flexibility

|                    |                                                                                                                                                               |          |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| <b>Integration</b> | All components that are not reasonably expected to be adapted separately are fully integrated into separate elements, including all parts of the system       | <b>4</b> |
|                    | Most of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all parts of the system     | <b>3</b> |
|                    | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system | <b>2</b> |
|                    | Few of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including only part of the system      | <b>1</b> |
|                    | None of the components that are not reasonably expected to be adapted separately are integrated into separate elements.                                       | <b>0</b> |

### 7.2.3.6 Interface simplicity

The scoring of the interface simplicity characteristic is inspired by the scoring of the type of connections by Cottařava and Ritzen (2020). The score is determined based on the effort required to connect, disconnect, or reconnect interfaces. Dry connections include regular dry connections where no adhesive or fastener is used, click connections, Velcro connections, or magnetic connections. Connections with added elements use for example corners, screws, or bolts and nuts for fastening. For direct integral connections, pins or nails can be used. Kit or foam are examples of soft chemical compounds that can be used to connect interfaces and glue, pitch, cement bond, and chemical anchors are examples of hard chemical connections.

Table 24: Scoring of the interface simplicity characteristic of flexibility

|                             |                                 |          |
|-----------------------------|---------------------------------|----------|
| <b>Interface simplicity</b> | Dry connections                 | <b>4</b> |
|                             | Connections with added elements | <b>3</b> |
|                             | Direct integral connection      | <b>2</b> |
|                             | Soft chemical compound          | <b>1</b> |
|                             | Hard chemical connection        | <b>0</b> |

### 7.2.3.7 Overcapacity

For the scoring of the overcapacity characteristic, both overcapacity with regards to building services and load-bearing capacity are taken into consideration. The degree of overcapacity concerning building services is assessed based on Geraedts' (2016) assessment score for the surplus of facilities and shafts and is shown in Table 25a.

The degree of overcapacity for the load-bearing capacity is based on the imposed floor loads the element is capable of carrying. The scoring is based on the imposed floor loads as prescribed by the Dutch National Annex of Eurocode 1991-1-1 (Nederlands Normalisatie-instituut, 2019a). The minimum value is based on the lowest imposed floor load included in the National Annex of 1.75 kN/m<sup>2</sup> for non-communal spaces in residential buildings in combination with the imposed floor load for light movable partitions of 0.5 kN/m<sup>2</sup>. A floor with this load-bearing capacity could only be applied in this specific use case. The maximum value for the load-bearing capacity is based on the maximum imposed floor load included in the National Annex, which is 5 kN/m<sup>2</sup> for various functions of areas where people may congregate, combined with a heavier version of movable partitions of 1.2 kN/m<sup>2</sup>. A floor with this load-bearing capacity could be used for all uses-cases outlined in the National Annex of Eurocode 1991-1-1. The normal scoring of the load-bearing overcapacity includes all residential and office functions, associated with a maximum imposed floor load of 3 kN/m<sup>2</sup>, in combination with medium weight movable partitions of 0.8 kN/m<sup>2</sup>. The high scoring covers all load-bearing capacities between normal and maximum. Table 25b gives an overview of the scoring of the load-bearing overcapacity of floor elements.

Table 25 shows which different combinations of building services overcapacity and load-bearing overcapacity are associated with which score or the flexibility characteristic of overcapacity.

Table 25: Scoring of (a) the building services overcapacity and (b) the load-bearing overcapacity

| <b>Surplus space for building services</b> |            | <b>Load-bearing overcapacity</b> |                              |
|--------------------------------------------|------------|----------------------------------|------------------------------|
| Best                                       | ≥ 50%      | Maximum                          | ≥ 6.2 kN/m <sup>2</sup>      |
| Better                                     | 30 - 50%   | High                             | 3.8 - 6.2 kN/m <sup>2</sup>  |
| Normal                                     | 10 - 30%   | Normal                           | 2.55 - 3.8 kN/m <sup>2</sup> |
| Bad                                        | No surplus | Minimum                          | ≥ 2.25 kN/m <sup>2</sup>     |

Table 26: Scoring of the overcapacity characteristic of flexibility

|                     |                                                                      |          |
|---------------------|----------------------------------------------------------------------|----------|
| <b>Overcapacity</b> | best/maximum; best/high; better/maximum                              | <b>4</b> |
|                     | best/normal; better/high; better/normal; normal/maximum; normal/high | <b>3</b> |
|                     | best/minimum; better/minimum; normal/normal; bad/maximum; bad/high;  | <b>2</b> |
|                     | normal/minimum; bad/normal                                           | <b>1</b> |
|                     | bad/minimum                                                          | <b>0</b> |

#### 7.2.3.8 Standardisation

The scoring of the standardisation flexibility characteristic is based on the number of different types of details and sizing used within the building component.

Table 27: Scoring of the standardisation characteristic of flexibility

|                        |                                               |          |
|------------------------|-----------------------------------------------|----------|
| <b>Standardisation</b> | Only 1 type of detail and sizing used         | <b>4</b> |
|                        | 2 types of details and/or sizing used         | <b>3</b> |
|                        | 3 types of details and/or sizing used         | <b>2</b> |
|                        | 4 types of details and/or sizing used         | <b>1</b> |
|                        | 5 or more types of details and/or sizing used | <b>0</b> |

### 7.3 Conclusions

Not all of the circularity assessment methods found through literature were relevant for building structures or at a building component level. For some of the methods, not the full method was available. Based on applicability for building products and availability, the Building Circularity Indicator is the assessment method found to be most relevant for the study at hand and will thus be used to assess the circularity of the existing floor designs and proposed design concepts.

There are different versions of the Building Circularity Index available for use in this research project. These include the original method by Verberne (2016), the version with revised disassembly factors and no weight normalisation by Van Vliet (2018), the version specialised for the assessment of foundations by Van Schaik (2019), and the Predictive BCI by Cottafava and Ritzen (2020) which includes the disassembly factors in the MCI and uses simplified disassembly factors. For this research project, the original method by Verberne will be used as it contains the most complete set of disassembly factors.

No suitable method for the assessment of the flexibility of building components was found in the existing literature. The option of adapting the disassembly factors of the BCI assessment method to include flexibility was considered but was dismissed based on concerns over the accuracy of the resulting circularity score and the lack of a distinguishable flexibility score. A new flexibility assessment method for application in this research project was developed based on the technical characteristics of flexibility as identified in Chapter 5.1.

# Part III: Case study



Part III concerns the case study, where the theoretical framework is placed in a practical context. based on sub-questions 5 to 10. First, the current design by Van Wijnen is presented and evaluated along with the other existing floor designs. Then, new design concepts are developed based on the evaluation of the existing floor designs and the building code and stakeholder requirements. Finally, the new design concepts are assessed and evaluated within their broader context.

## 8 Current design

The current design for the floor system is the point of departure for the case study. First, the current floor design by Van Wijnen is introduced and its properties are presented. Then, the current floor design, as well as the previously identified existing flexible floor systems and traditional floor systems, are assessed and evaluated on their degree of circularity and flexibility.

### 8.1 Floor design by Van Wijnen

The current floor design is part of the Fijn Wonen housing concept by Van Wijnen. In accordance with sub-question 4, first, the dimensions of the floor design will be discussed followed by the structural and technical properties, and the building services integrated in the design. The floor system is still under development and thus still subject to change. Certain properties are not included in this description, due to confidentiality.

#### 8.1.1 Dimensions

The floor system consists of solid prefabricated floor elements that are positioned next to each other. There are different versions of the Fijn Wonen concept, Figure 52 shows a representative illustration of a storey floor principle of one of these concepts. The figure shows the four floor elements that make up the floor surface. Each floor element has its own width, ranging from 1538 mm to 3230 mm. The housing depth is either 8.4 m or 9 m. This difference in depth is covered by using A-floor elements of different widths. The span of the floor elements depends on the housing width, which can be 5.1, 5.4, 5.7, or 6.1 m. The ground floor and storey floor have a height of 200 mm. If a flat roof is applied, the roof floor has a height of 180 mm. The highest storey floor is placed at a height of 5.62 m.

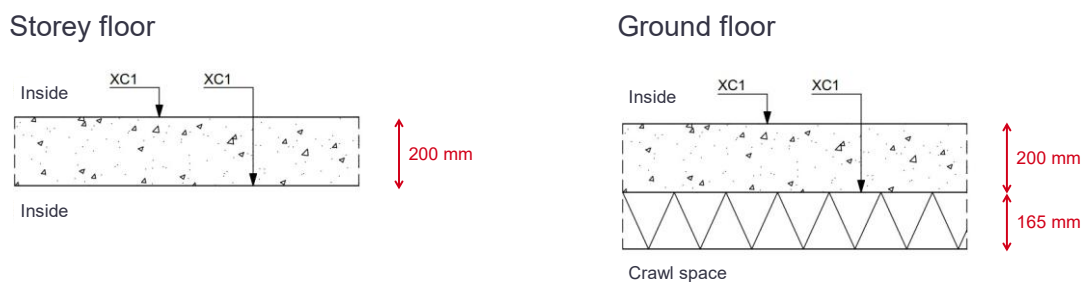


Figure 51: Side view of storey floor and ground floor

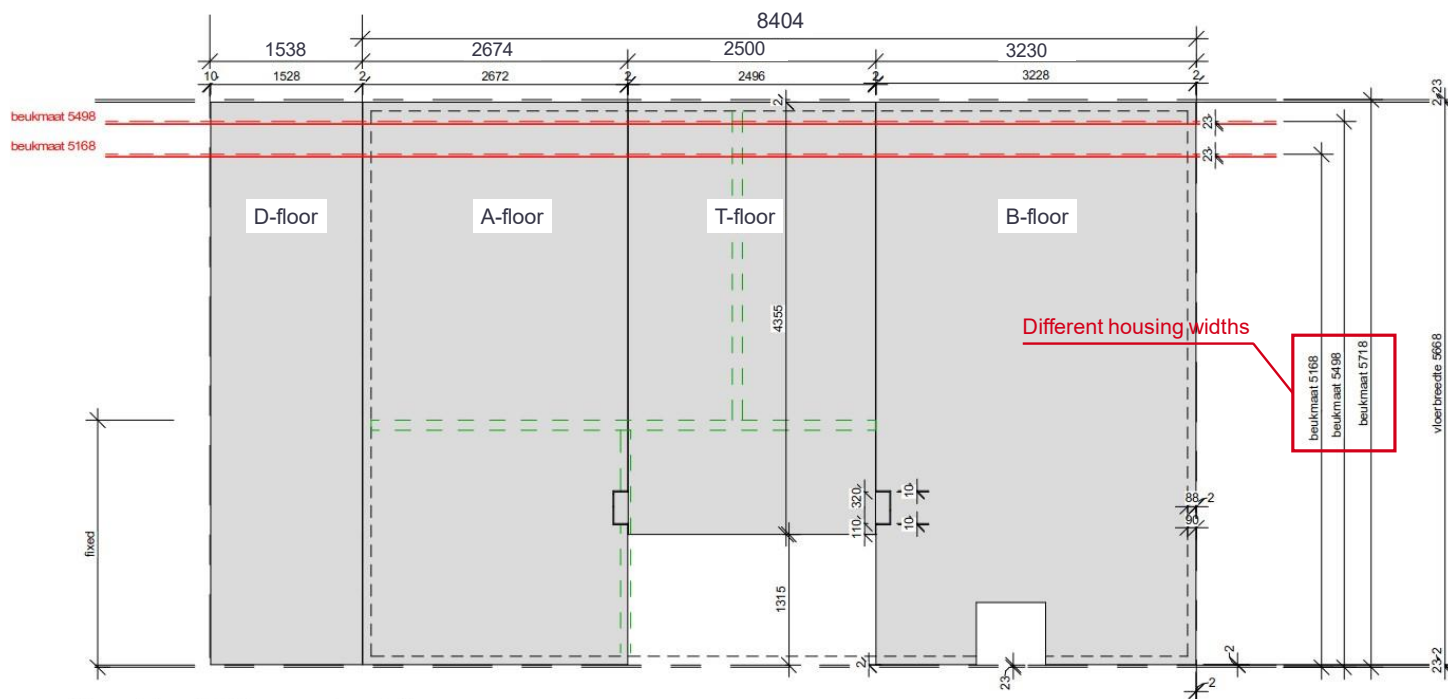


Figure 53 also includes the weight and height of the current design. Notably, the current design has a lower height than almost all of the other designs, with the exception of the Lignatur floors. The current floor design is within the same weight range as the VBI and Dycore piping floor and HOLCON floor. It is heavier than all other hollow space floors, the hollow core slab, and the Wing floor. Only the precast lattice slab is considerably heavier than the current design.

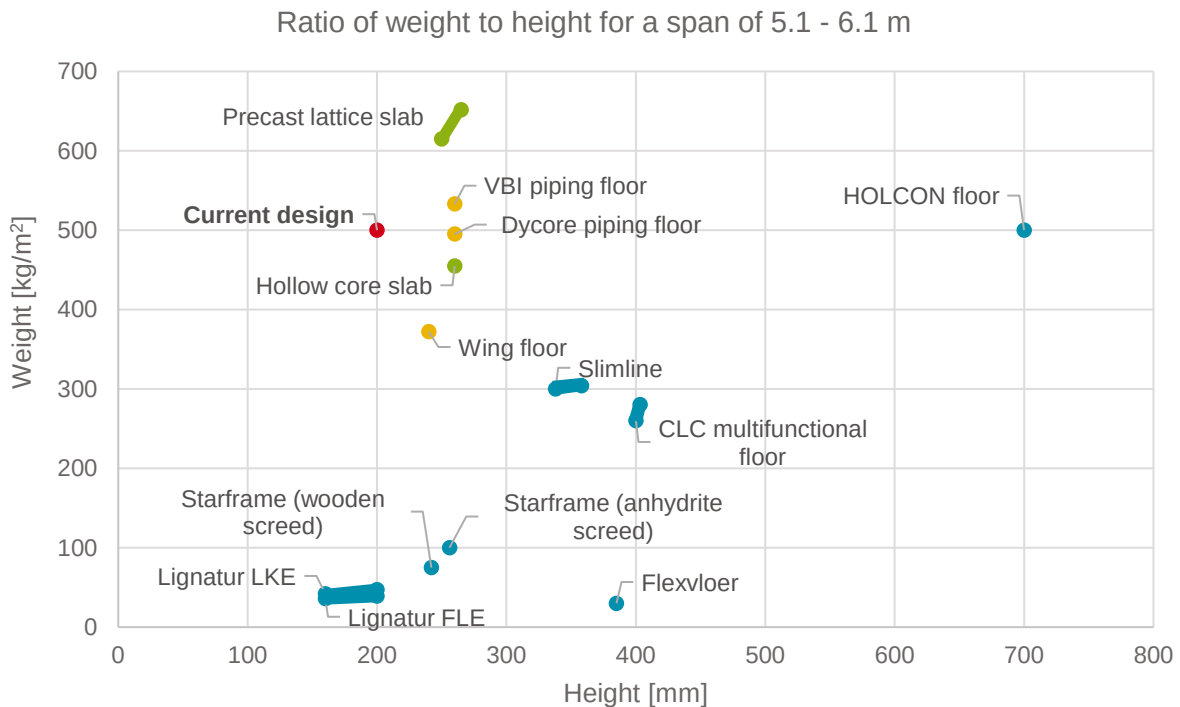


Figure 53: Weight-to-height ratio for a span of 5.1 to 6.1 m

### 8.1.3 Building services

The building services are cast into the floors. They are placed in the middle of the floor element, where the forces are taken up by the reinforcement and compression zone. The building services are either placed in the direction of the span or perpendicular to the span. The building services cast into the floor include the electrical supply, water supply, and sewage system. In the storey floor, the building services take up a height of up to 168 mm. For the ground floor, some of the building services are connected to the crawling space below.

## 8.2 Assessment of current design

The circularity and flexibility of the current floor design are assessed to learn how the design can be improved. This assessment is done using the assessment methods selected in Chapter 7. In addition to the assessment of the current design, a couple of the existing solutions identified in Chapter 6, and two traditional floor systems are also assessed. This is done to provide ground for comparison and to identify the effect of different design choices and types of solutions on the circularity and flexibility of the floor systems. The results from the circularity and flexibility assessments are evaluated to see where improvement is possible in the circularity and flexibility of the current design and how these aspects are dealt with in other existing designs.

## 8.2.1 Circularity assessment

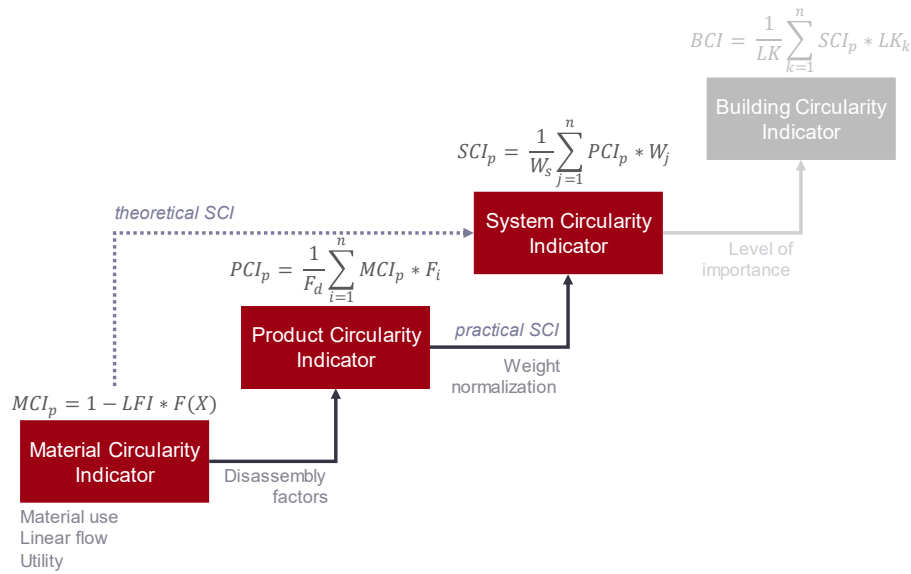


Figure 54: Structure for the BCI assessment model, adapted from 'Assessment model - conceptual structure for the circularity assessment model of materials within the technical cycle' (Verberne, 2016)

The BCI method as developed by Verberne (2016) is applied to the current design of the floor system, the traditional floor systems of the hollow core slab and precast lattice slab, as well as to a number of the existing solutions for flexible floor systems. The inclusion of the existing solutions in the circularity assessment is dependent on the availability of the required information. The structure of the BCI assessment method is illustrated in Figure 54. First, the Material Circularity Indicator is determined for each component of the floor. Then, the disassembly factors are included to calculate the Product Circularity Indicator. All products that make up the floor are normalized by weight to come to the System Circularity Indicator. As this circularity assessment is limited to the floor systems only, the final step of calculating the Building Circularity Indicator is omitted. The formulas used to calculate the different indicators and the assessment of the different floor systems can be found in Appendix H.

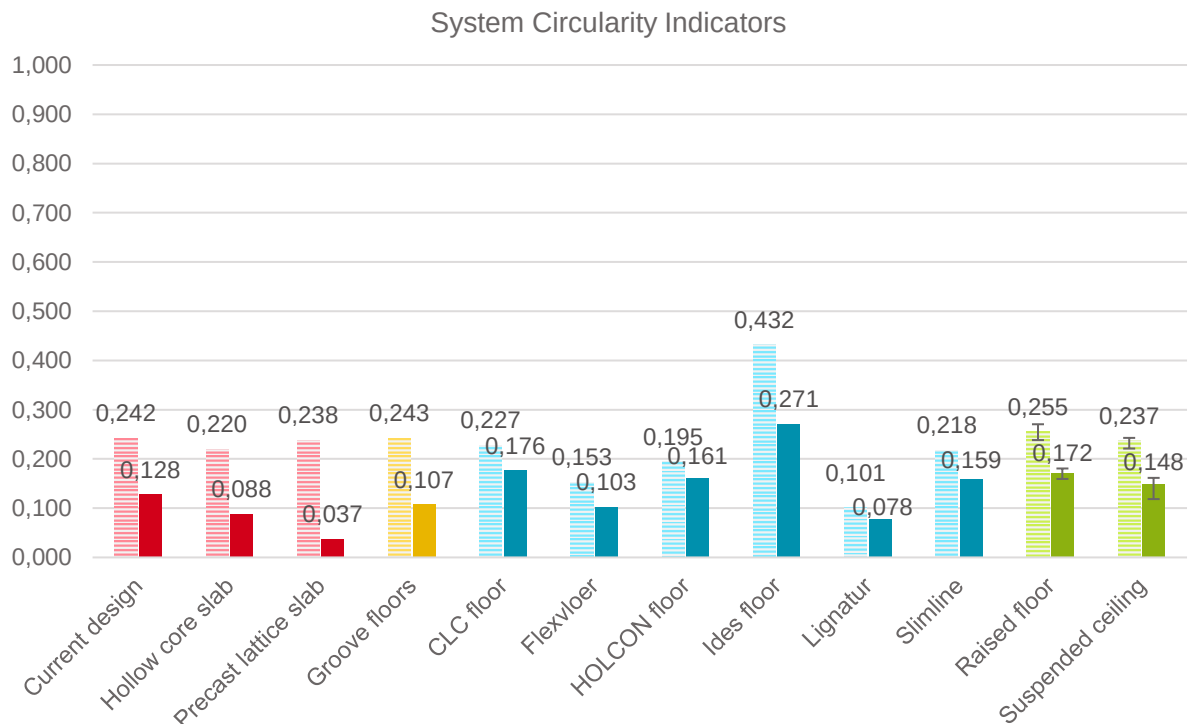


Figure 55: Comparison of circularity scores, each floor gives a theoretical value (left) and a practical value (right)

Figure 55 shows the SCI values for all of the floors that are assessed on their circularity. The theoretical SCI, based on the MCI, is shown on the left for each floor. The practical SCI, which is based on the PCI and thus includes the disassembly potential, is shown on the right. The full assessment of the floor systems can be found in Appendix H.

To assess the floor systems, information is used from NIBE (2019), GWWmaterialen (2014), and Dias (2003), as well as the information gathered in Chapters 6 and 8.1 on the existing solutions and the current design respectively. Where other sources are used, this is indicated in Appendix H. It should be noted that the total weight in the assessment does not always exactly match the own weights specified in the product information. This is due to unavailability of specific material information and thereby the use of more general material weights. The assessment is done based on the versions of the existing solutions that could be used in the situation the current floor is designed for, which is a residential building with a floor span ranging from 5.1 to 6.1 m. For every material used, no non-virgin material input is assumed as none of the floor designs explicitly state the use of re-used materials. This assumption does negatively affect the MCI value significantly.

Only the elements of the floor systems belonging to the structural layer are included in the assessment, with the exception of the raised floor and suspended ceiling systems. According to NIBE (2019), these systems have a service life of approximately 25 years. When assessing these systems as a structural layer, this results in an MCI of 0. This result is not useful for the comparison and is unfair to the systems as they do not take part in the load-bearing function of the building structure. The raised floor system only has to bear the load placed directly on top of it and transfer them to the load-bearing floor underneath. The suspended ceiling system merely needs to bear its own weight and that of the building services placed on top. As these structures are installed to provide a space for the building services, these designs are assessed as part of the building services layer.

The different groove floors are included in a single assessment as there are no significant differences in material used or disassembly potential between the different designs. The raised floor and suspended ceiling systems were assessed in combination with commonly used load-bearing floors. This is done to ensure a fair comparison with the other floor designs, as the mass and material use required for a load-bearing floor is automatically included in the other assessments. The raised floor and suspended ceiling systems were combined with a solid cast in situ concrete slab, a hollow core slab with and without structural topping, and a precast lattice slab. The resulting range of the SCI values is indicated in Figure 55. The hollow core slab including a structural topping and the precast lattice slab are also assessed separately from the raised floor and suspended ceiling system for inclusion in Figure 55.

Regarding the MCI, the Lignatur floor and the Flexvloer have the lowest values, followed by the HOLCON floor. Although the utility factor of both timber floor designs is high, their MCI is brought down due to a low reusable output, resulting in a high Linear Flow Index. The low reusable output can be traced back to the materials used. According to NIBE (2019), the primary disposal scenario for these timber floors is incineration, which is not a form of reusable output. This disposal scenario for timber is supported by other sources, however, it should be noted that there are also sources that indicate that a higher degree of reuse of timber is more realistic (Beyer et al., 2010; John & Buchanan, 2013; van Belzen & Klaassen, 2021). The reusable output for the Flexvloer is slightly higher than for the Lignatur floor because it combines timber with flax panels, the latter have a high reusable output according to NIBE (2019). The HOLCON floor scores only slightly lower than the other floors that use concrete, such as the current design, the groove floor, the CLC floor, and the Slimline floor. This is the result of a slightly lower reusable output, which can be traced back to the calcium sulphate plate used to cover the opening in the top concrete slab that grants access to the building services in the hollow space.

Independently, the raised floor and suspended ceiling systems have the highest MCI. This is mainly due to these systems being assessed at part of the services layer, associated with a system lifetime of 15 years, and having an expected service life of 25 years (NIBE, 2019). As a result, the utility factor for these independent systems is overstated in the assessment. The high MCI is brought down in the theoretical SCI value through the inclusion of the load-bearing floor. The Ides floor also has a high MCI value, due to a combination of a high reusability of the material and a relatively high utility factor.

The traditional floor systems score the lowest on the disassembly determining factors of the PCI. The precast lattice slab scores low or lower than average on all of the disassembly factors. The hollow core slab scores slightly better than the precast lattice slab due to a higher score on the geometry of the

product edge and on the accessibility of its connections and its prefabricated nature. The current design and the groove floor also score low on the disassembly determining factors. The current design improves on the hollow core slab due to the demountable design of the connections. The groove floor scores the same as the hollow core slab on all aspects, except for the functional independence as, although they are integrated, the different functions do have their own space within the floor system. The other floor designs score better on the disassembly potential. Independently, the raised floor and suspended ceiling systems score the highest, distinguishing themselves from the other designs through high scores on functional separation and functional independence.

Overall, as can be seen clearly in Figure 55, the Ides floor has the highest SCI values. This is the result of its high MCI value due to the high reusability of the materials and a relatively high utility factor. The determination of the PCI value continues on the MCI value. Therefore, the Ides floor also has a high PCI value and thus a high practical SCI value as a result of a high initial MCI value and an average score on the disassembly factors.

The Flexvloer and the Lignatur floor have the lowest theoretical SCI values, established by their low initial MCI values. It is noticeable that the theoretical SCI values of the traditional floors are among the highest behind the Ides floor, but the practical SCI values of these floors are among the worst values in the comparison. A similar, although less drastic, drop-off between the theoretical and practical SCI values of the current design and groove floors can be noted. This means that the practical circularity of these floors, as a result of the disassembly potential of the systems, are not in line with their theoretical circularity as a result of only the material use.

## 8.2.2 Flexibility assessment

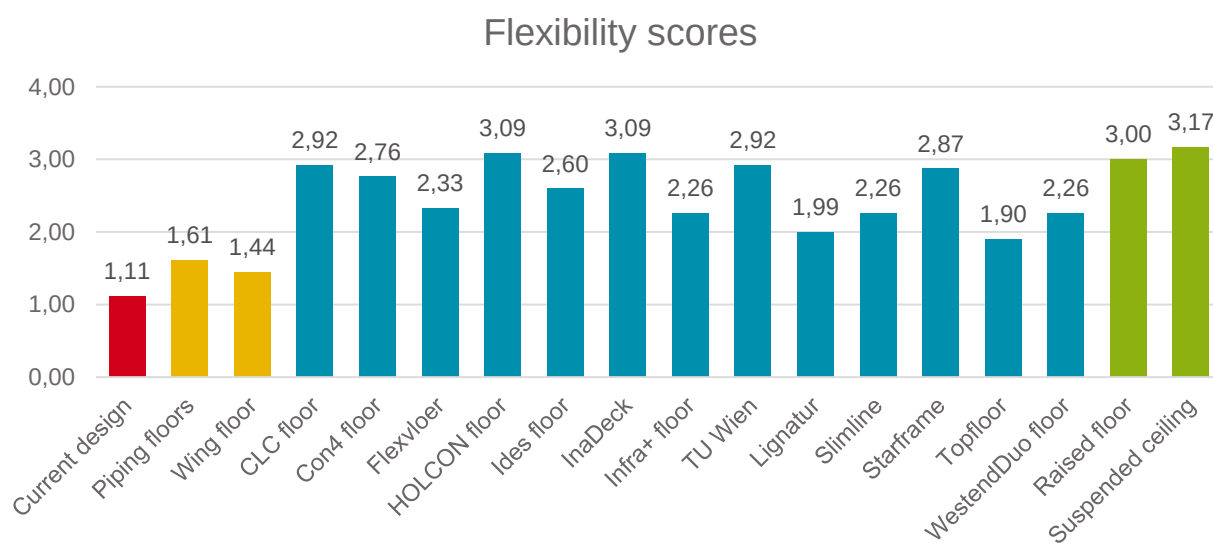


Figure 56: Comparison of flexibility scores

The flexibility assessment method is applied to the current design for the floor system and to the existing solutions for flexible floor systems. In Figure 56 the overall flexibility scores of the floor systems are presented. Figure 57 gives the individual network diagrams of each floor system. The scores of the existing solutions are indicative values, as the scoring include a number of assumptions due to lack of information. The full assessment, including the rationale behinds scores and assumptions, can be found in 0.

When looking at the flexibility scores in Figure 56 it is notable that the current floor design has the lowest score. Here, it should be pointed out that the current floor is not yet designed with flexibility in mind, while for the other floor systems this is at least partially the case. The floors with grooves, shown in yellow, score slightly better than the current design, but not by a large margin. The hollow space floors, indicated in blue, score better than both the current design and the groove model floors, with scores ranging from just higher to significantly higher. The floors shown in green, the raised floor and suspended ceiling systems, score both within the range of the highest scores given. The suspended ceiling system is



awarded the overall highest flexibility score. This system scores especially high when looking at accessibility, independence, and overcapacity. The HOLCON floor and the InaDeck share the second-highest score. Both floors score particularly high on overcapacity and standardisation but also score at or above average for the other flexibility characteristics. The raised floor system has the third-highest score, the only other system to score a three or higher. The scores for this system are very similar to the suspended ceiling system, only scoring slightly lower on overcapacity.

Regarding the individual score for the characteristic of accessibility, the current design, the Lignatur floor, and the Topfloor share the lowest score. This is because for these floors the buildings services are either cast into or placed behind structural elements, meaning that damage to the load-bearing elements is required to access them. The best accessibility scores are rewarded to the raised floor and suspended ceiling systems as these only require the lifting of a panel for access to the building services. The accessibility of the current design could be improved by not casting the building services into the floor. The building services should not form one technical element with the load-bearing structure, in order to prevent damage to the load-bearing floor when access to the building services is required. This issue is also addressed under the characteristic of independence. To further improve accessibility, the coverage of the building services should be removable through a non-damaging operation or no operation at all.

The durability characteristic is assessed based on the research done by Dias (2003) on estimating the useful lives of structures in different materials, maintenance levels and environments. For all floors, a dry and non-aggressive environment is assumed in accordance with indoor conditions. The lowest scores are awarded to the raised floor and suspended ceiling systems. These systems are not made out of common structural materials and are therefore not well represented by the research of Dias (2003). A lower than average score is assumed because they are not load-bearing systems and therefore assumed to be less robust. The durability of the current design could be improved by considering the use of a different structural material than traditional reinforced concrete.

Considering the design characteristic of independence, the current design scores very low as all the parts are cast into the floor to form one element. The floors with grooves score slightly better because the building services have got their own space within the floor but are still usually cast into place. The independence scores for the hollow space floors are higher because the building services have their own space within the floors and are not fixed in place. The highest scores are earned by the raised floor and suspended ceiling systems, due to the full separation of the structure and the building services zones. The improvement of the independence of the current design should start by providing a separate zone for the building services within or outside of the load-bearing floor.

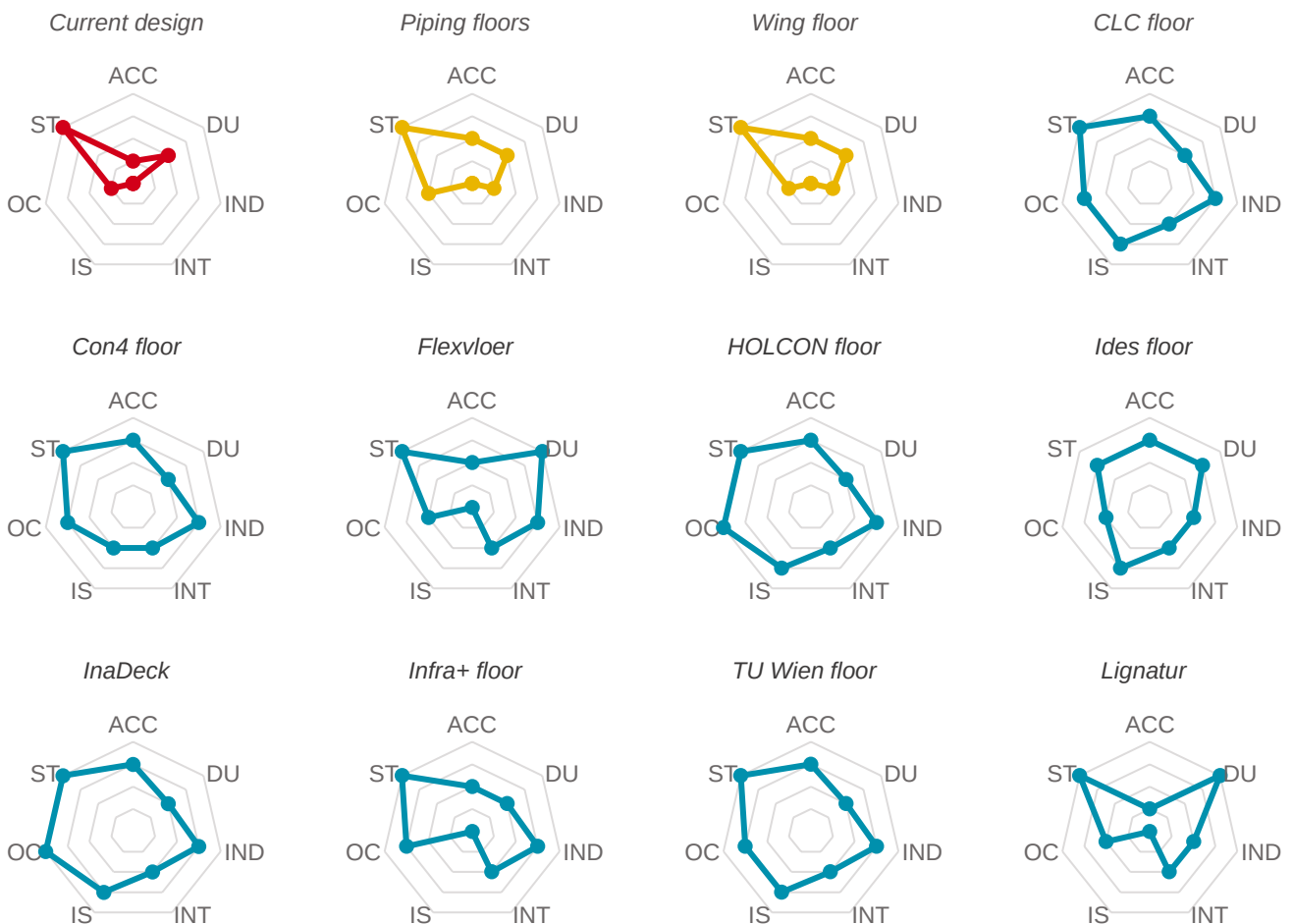
Integrations, as represented in these scores exclusively, concerns the integration of the structural components into one technical element. The structural components are not expected to require adaptation separately. The current design and the grooves floors are scored at 0 for integration because the components that are expected to be adapted separately are altogether incorporated into one technical element. The other floor designs are all rated at partial integration because the integration only concerns the load-bearing structure. The different functions of building services are not integrated into their own separate technical elements. The integration rating of the current design could be improved if the building services are separated from the load-bearing structure, so the load-bearing elements could form their own separate integrated system.

For interface simplicity, the lowest scores are assigned to the designs where the different parts are cast into place. The high scores are given to the floors with removable screeds or top panels that use connections with added elements, like screws. This way the panels are kept in place but are still easily removable with standard tools. No floors were awarded the highest possible score, as none of the floors employ fully dry connections. The first steps for improving the interface simplicity of the current design can be made by no longer casting all elements of the floor into place. The cement bonding between the elements now results in a hard connection. This improvement in interface simplicity is congruent with the need to improve the independence of the different floor parts.

When it comes to overcapacity, the floors that are designed for spans that are larger than commonly used in residential buildings score high, as they have a larger load-bearing overcapacity by default. Many of the other floor systems are available in a range of spans and heights, and thus a different height could be chosen for these floors to realise a larger load-bearing overcapacity. For the hollow space floors, often a larger load-bearing overcapacity goes hand in hand with a larger structural height and thus a

larger surplus space for building services. The surplus space for building services is also influenced by the frequency and size of the web openings in the transversal direction of the hollow space. The suspended ceiling system also scores very high when it comes to overcapacity. For this system, the load-bearing overcapacity is not taken into consideration, as a load-bearing capacity is not required at the bottom side of the floor. For the current design, an increased load-bearing overcapacity is a matter of choosing a floor element with a larger height, perhaps intended for larger spans. Currently, there is little to no surplus space for building services in the design. There are limited areas in the floor where the full available height is not yet occupied. In choosing a floor element that can bear larger loads, the floor height and thus the available space for building services are also likely to increase. Here, of course, the interplay between overcapacity, efficient material use, and floor height should be taken into consideration. The degree to which load-bearing overcapacity is desired should be considered, for example by evaluating what the realistic future use or reuse scenarios are for the floor system.

The scores for the characteristic of standardisation are pretty high overall. There was not a lot of information available on the different sizes within the existing floor designs or the different types of connections used. Because most of the floor systems do not consist of many different parts, it was assumed that not many different types of connections are used. In addition, most of the designs are intended for industrial production and are thus likely to be highly standardised.



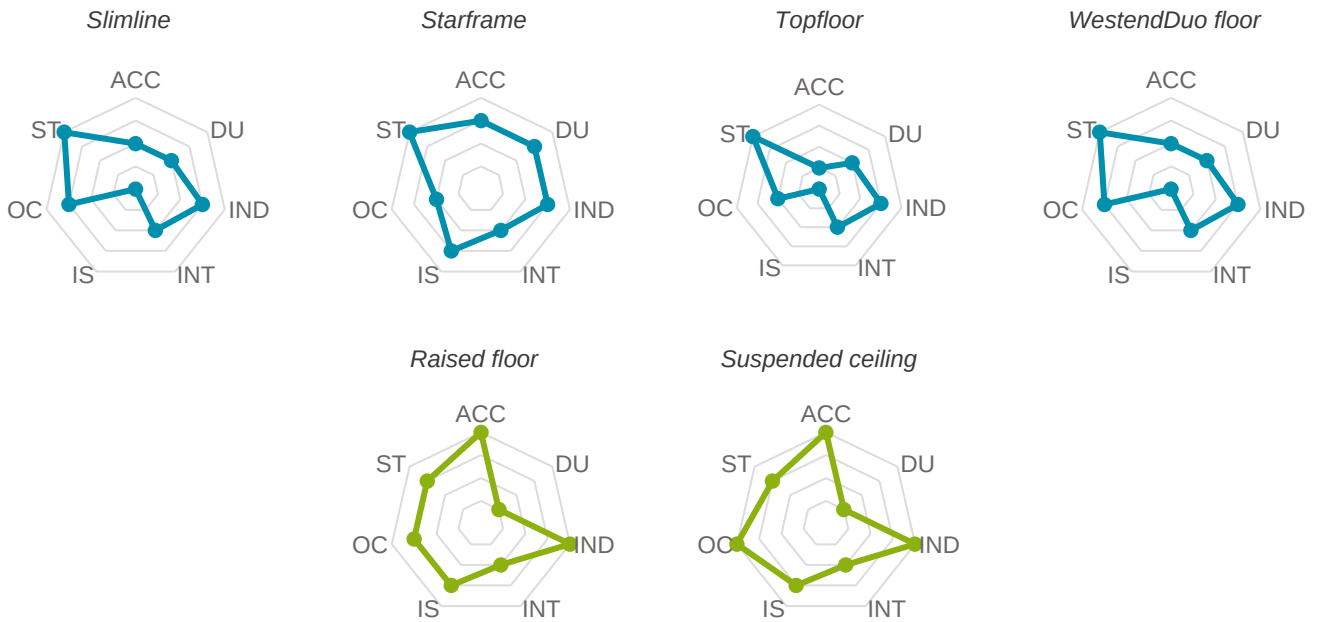


Figure 57: Network diagrams of flexibility scores

### 8.2.3 Evaluation

In general, the SCI scores of the different floor designs are not very high. The circularity of the current floor design could be improved by increasing the disassembly potential to keep the practical SCI more in line with the theoretical SCI. The MCI value needs to be improved in order to increase the overall SCI values of the current floor design. This can be achieved by using a material or system with a higher expected service life to increase the utility factor and by considering the use of non-virgin material input.

The flexibility score of the current floor design is quite low. Looking at the individual scores of the flexibility characteristics, a couple of points of improvement were identified. The accessibility, independence and interface simplicity can be improved by no longer casting the different parts of the floor into place. Currently, all parts, regardless of function and service life, form one technical element. The accessibility can further be improved by applying a removable coverage at the top or bottom of the floor. To improve the durability of the floor element, different materials from the traditionally used reinforced concrete could be considered. Both a load-bearing overcapacity and surplus space for building services can be realised by increasing the floor height. For this design choice, the interplay between flexibility and the circularity aspect of material efficiency is of importance and should be thoroughly considered.

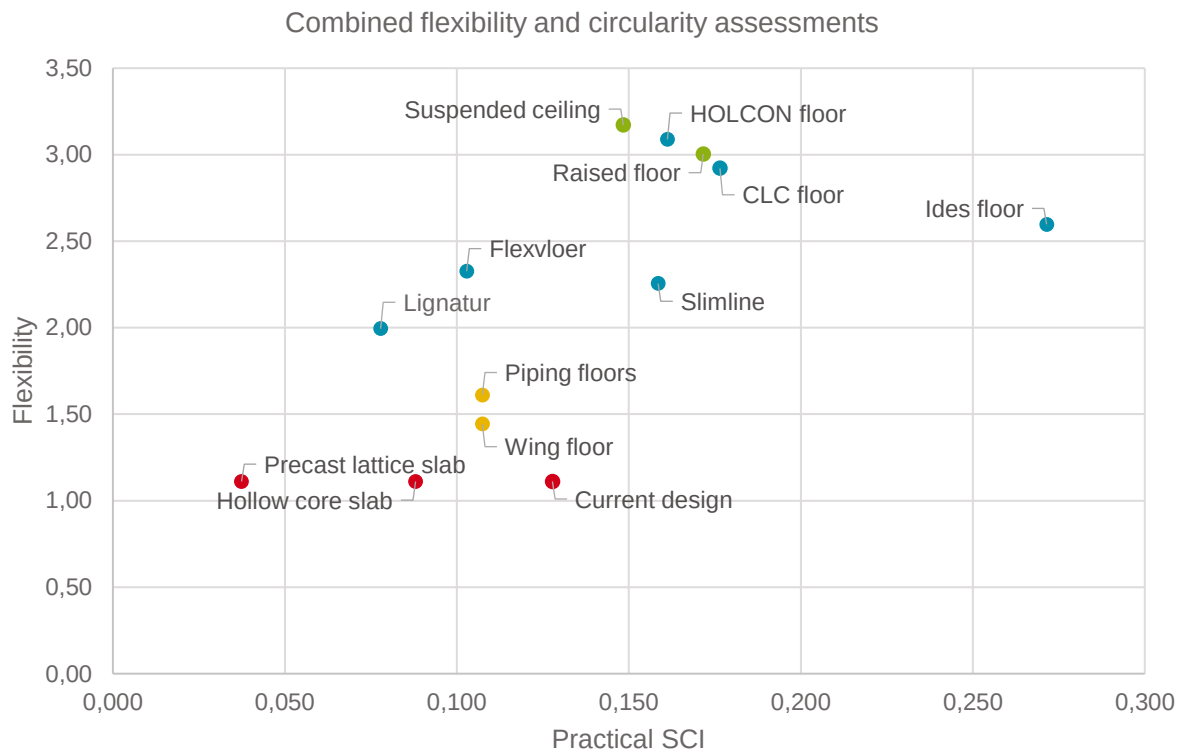


Figure 58: Combined circularity and flexibility assessments

Figure 58 gives the flexibility scores of the different floor systems plotted against their practical SCI values. For the inclusion of the hollow core slab and the precast lattice slab, the same flexibility score as for the current design is used as the flexibility of these systems do not differ significantly. With exception of the Ides floor and the precast lattice slab, the assessments of the circularity are not particularly spread out. The flexibility scores show a larger spread.

The current design scores on the low side for both assessments. The traditional floor systems score lower on circularity than the current design and have a similar flexibility, as previously mentioned. The groove floors also score worse on the circularity assessment, due to a lower disassembly potential with regard to the connections and their accessibility. These floors have a higher flexibility score as a result of a slight improvement on accessibility, independence, and overcapacity for building services in comparison with the current design. After the traditional floor systems, the wooden floors, the Lignatur floor and the Flexvloer, score the worst on circularity. These floors hold the middle ground for flexibility. The CLC floor and the HOLCON floor, both hollow space floors that are made using concrete, and the raised floor and suspended ceiling systems score within the same range at the top of Figure 58. Here, it is noteworthy that the latter two are combined with concrete load-bearing floors for the circularity assessment. When looking at the correlation between the circularity and flexibility scores, it is noticeable that the floors on the left side of the graph, with a lower circularity score, generally have a lower flexibility score than those on the right side of the graph.

## 9 Development of new design

Based on the information gathered on flexible design in the theoretical framework and the evaluation of the existing floor design, new design concepts are developed with the aim to improve the flexibility of the floor system. In order to develop designs that are feasible in practice, first, the requirements for the design of a floor system are compiled. Then, these requirements and the flexibility measures are applied in the design process.

## 9.1 Requirements

The relevant requirements for the design of the floor system are gathered to set up a framework within which design changes can be implemented. The overview of the requirements is important to ensure that the design complies with all prerequisites. Two types of requirements are addressed. The building code requirements include legal obligations based on the Eurocode and Dutch Building Decree, and the stakeholder requirements concern demands and wishes from different stakeholder parties involved.

### 9.1.1 Building code requirement

Appendix J contains an overview of the relevant building code requirements found in the Dutch Building Decree and various Eurocode documents. Here, a summary is given of the key requirements.

Structurally, the Dutch Building Decree dictates that a floor should not fail during its lifetime under the combination of actions for accidental design situations as defined in NEN-EN 1990 (*Bouwbesluit 2012*, 2021). For residential buildings, the indicative design working life is 50 years (Nederlands Normalisatie-instituut, 2019c). The combination of actions for accidental design situations can be determined using the expressions 6.11a and 6.11b as given in Eurocode 1990 (Nederlands Normalisatie-instituut, 2019c). The design values for action due to impact can be found in the Dutch National Annex for NEN-EN 1991-1-7 (Nederlands Normalisatie-instituut, 2016). For the variable load, category A for domestic and residential buildings is considered (Nederlands Normalisatie-instituut, 2019d). For non-communal floors, a uniformly distributed load of  $q_k = 1,75 \text{ kN/m}^2$  and a concentrated load of  $Q_k = 3 \text{ kN}$  should be applied. An additional  $0.8 \text{ kN/m}^2$  is added to the uniformly distributed variable load to account for movable partitions on top of the floor. This comes down to a total uniformly distributed variable load of  $2.55 \text{ kN/m}^2$ .

For the serviceability limit state, the deflection and vibration of the floor should be addressed (Nederlands Normalisatie-instituut, 2019c). The maximum deflection of the floor depends on whether the floors are carrying crack-sensitive walls or not, it is assumed that this is the case. Vibrations are usually not an issue for residential buildings, except in the case of exceptionally light floors.

There are different requirements for fire resistance based on where the floor elements are situated within fire-compartments and in relation to escape routes. In line with flexibility, it is assumed that the floor element should comply with the highest requirement so it can be used at any location in the building. Based on a common storey height of 3 m, it is assumed that virtually all ground-level residential buildings fit within the category of buildings with a height of  $\leq 7 \text{ m}$  high building category, requiring 60 minutes of fire resistance (*Bouwbesluit 2012*, 2021). According to the Dutch Building Decree, a fire class of  $D_{f1}$  is applicable. The assessment of the fire class requires testing in accordance with EN ISO 9239-1 and EN ISO 11925-2 with 15 seconds exposure time (Nederlands Normalisatie-instituut, 2019b). As such testing is outside of the scope of this research, the fire class will not be further considered.

As for the acoustic requirements, the characteristic air sound level difference between residential spaces within the same housing unit should not be smaller than 32 dB. The weighted contact sound level for sound transmission between two residential spaces within the same housing unit should not be larger than 79 dB (*Bouwbesluit 2012*, 2021).

### 9.1.2 Stakeholder requirements

The stakeholder requirements are not as firm as the requirements from the building codes and the production process. They include aspects that are important for the stakeholders and therefore important for the success of the implementation of the floor system (Gan & Guo, 2014). In order to recognise the interests of the different stakeholders, a rudimentary stakeholder analysis is done (van Bueren, 2020).

First, the stakeholders that are relevant to the design of floor systems are identified. The stakeholders include the parties that are involved in the design process, such as the architect, the building services company, and the structural engineer, parties involved in the execution of the construction processes, such as the manufactures and the contractor, as well as the client or investor, who commissions the project, the end-user, who can be either a tenant or a homeowner, and finally, the municipality responsible for the policy and legislation in the area. Table 29 gives an overview of the different stakeholders, their interests, and their power (Gan & Guo, 2014; van Bueren, 2020). The interests and powers are based on assumptions based on context in combination with information gathered during the

interviews for research question 1b. Figure 59 shows the different stakeholders in a power-interest grid. The grid gives insight into the level of interest of the stakeholders in combination with their power to enforce their interests.

Table 29: Stakeholders and their areas of interest and source of power

| Stakeholder               | Areas of interest                                                                                                                          | Source of power                                       |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Architect                 | Realisation of the client requirements in a satisfactory design.                                                                           | Knowledge, experience, creativity                     |
| Building services company | Realisation of the client and building physics requirement, in a satisfactory and simple solution.                                         | Knowledge, experience, creativity                     |
| Contractor                | Efficient building process, satisfactory end product, and reasonable profit margins.                                                       | Knowledge, experience, production                     |
| End-user (owner)          | Living comfort, preservation or improvement of property value.                                                                             | Legal rights (e.g. property rights)                   |
| End-user (tenant)         | Living comfort and preservation of living comfort.                                                                                         | Legal rights (e.g. rent protection)                   |
| Investor (developer)      | A valuable end product that can be sold against a good profit margin.                                                                      | Financing of the project                              |
| Investor (management)     | A valuable product that can be rented out against a good profit margin, property value preservation, and low maintenance costs and effort. | Financing of the product                              |
| Manufacturer              | Efficient building or supply process and reasonable profit margins.                                                                        | Supply of products                                    |
| Municipality              | Housing for citizens, positive image, and positive spatial development.                                                                    | Issuing permits, enforcing zoning plan, grant funding |
| Structural engineer       | Realisation of the client and structural requirements, in a satisfactory and simple solution.                                              | Knowledge, experience, creativity                     |

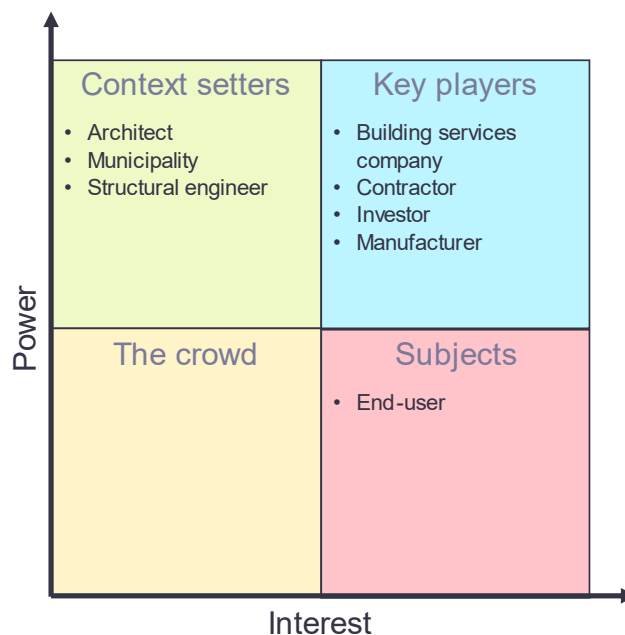


Figure 59: Stakeholder power-interest grid



As a result of the stakeholder analysis, a couple of topics can be identified that should be taken into consideration during the design process. The first topic is finance. The financial side of floor design and design in general is of interest to most of the stakeholders. It is especially important to the investor, who will have to finance the entire project. The investor wants to ensure a good profit margin and would therefore want to optimise the ratio between investment costs and sale or rental revenue. The financial side is also of interest to the contractor and manufacturers who have to make a competitive bid on the project while still ensuring a sufficient profit margin for themselves. Even though the production costs of the floor system are not directly within the scope of this research, this topic should be discussed qualitatively due to its importance to the stakeholders and therefore the success of the design.

In relation to the financial side of design, as also became apparent in the interviews discussed in Chapter 5.2, the floor height is also of importance. In the built environment, there are often restrictions on the building height allowed. To optimise the profit, the investor wants to realise as much usable surface area as possible. Larger floor heights can be a restricting factor in the total number of building layers that can be realised and thus the total number of building layers that can be sold or rented out. On the other hand, the building service company requires at least a certain floor height for the incorporation of building services, this can be either within or separate from the structural floor height.

Simplicity or ease of construction is also of importance to a number of stakeholders. For the designing stakeholders, it is preferable if the solutions are not too complicated and can be readily worked out. For the executing stakeholders, a quick and efficient construction process is desirable. An uncomplicated assembly process requires fewer hours and less specialised work and reduces the chances of mistakes and associated failure costs.

For the end-user, the quality and comfort of living are most important. In day to day life, the end-user does not want to be concerned with the floor design. They mainly want the floor to function and to not experience any hindrance from it. In case of repairs, renovation, or upgrades it is in the end-users interest that the construction activities do not take too long and are not too intrusive to the rest of the structure and their lives. In the case of a homeowner, ease of maintenance, upgradability, and durability are of importance for the preservation of the property value.

## **9.2 Implementation of flexibility measures**

The evaluation in Chapter 8.2 shows that there is room for improvement when it comes to the flexibility of the current floor design. The results of this evaluation as well as the cost influencing factors from Chapter 6.4 provide input for a new floor concept. Different design choices are considered and evaluated based on flexibility, applicability and whether the requirements from Chapter 9.1 are satisfied to come to a new flexible floor design for use in residential buildings.

### **9.2.1 Initial considerations**

Based on the circularity, flexibility, and cost evaluations from Chapters 8.2 and 6.4, there are a couple of considerations that should be accounted for in the design process.

Based on the circularity assessment from Chapter 8.2.1, it can be concluded that circular material choices form the basis for a circular design. This can be achieved through the use of materials with a high degree of reusability and a high utility factor. Even though the use of non-virgin materials also positively influences the material circularity of a design, this design option is not taken into further consideration. In addition to circular material choices, the disassembly potential of a design also influences its overall circularity. Special attention should be paid to functional separation, functional independence, and technical life cycle coordination as these design factors are of importance to both flexibility and the disassembly potential. Moreover, the connections of the floor design should be standardised and accessible and should have a simple geometry to ensure a good disassembly potential. Preferably, the connections should be designed using mechanical connections rather than chemical connections.

From the flexibility evaluation in Chapter 8.2.2, it is evident that having no direct integration between the load-bearing floor and the building services is of importance to the flexibility of floor design. No direct integration of these functions positively impacts the flexibility characteristics of independence, integration, and interface simplicity. Furthermore, the accessibility of the building services is significant

to the flexibility of the floor design. Accessibility can be achieved through the use of removable panels on one side of the floor. Ideally, these panels are removable through non-damaging operations or no operations at all.

Because costs are an important aspect in the building industry, it is important to also take the cost influencing factors from Chapter 6.4 into consideration. The amount of material used and the total height of the floor structure should be taken into account for the design choices. In addition, the combination of elements of different materials within the floor design should be limited and minimal additional production operations would be preferred. Finally, it is preferable if the prefabricated floor element requires no propping during installation to expedite the construction process.

### 9.2.2 Span direction

There are different ways a floor span can be covered. The span distance affects the height of the element and is therefore important for the cost considerations. Three options for the span direction are considered, as illustrated in Figure 60.

Option A is in line with the current design, where the floor elements cover the full span in one direction. In this case, the largest span to be covered is 6.1 m. For option B, the floor elements cover a shorter span and are carried by beams that cover the larger span. The aim of this option is to investigate if the combination of a shorter span with beams allows for a smaller total floor height. To minimize the total floor height, the beam should be designed as an integrated beam. Option C concerns a flat slab carried by columns in the corners. In this case, the load is carried in two directions. According to Nassar and Al-Qasem (2020), this is the most economical system for residential buildings of reinforced concrete.

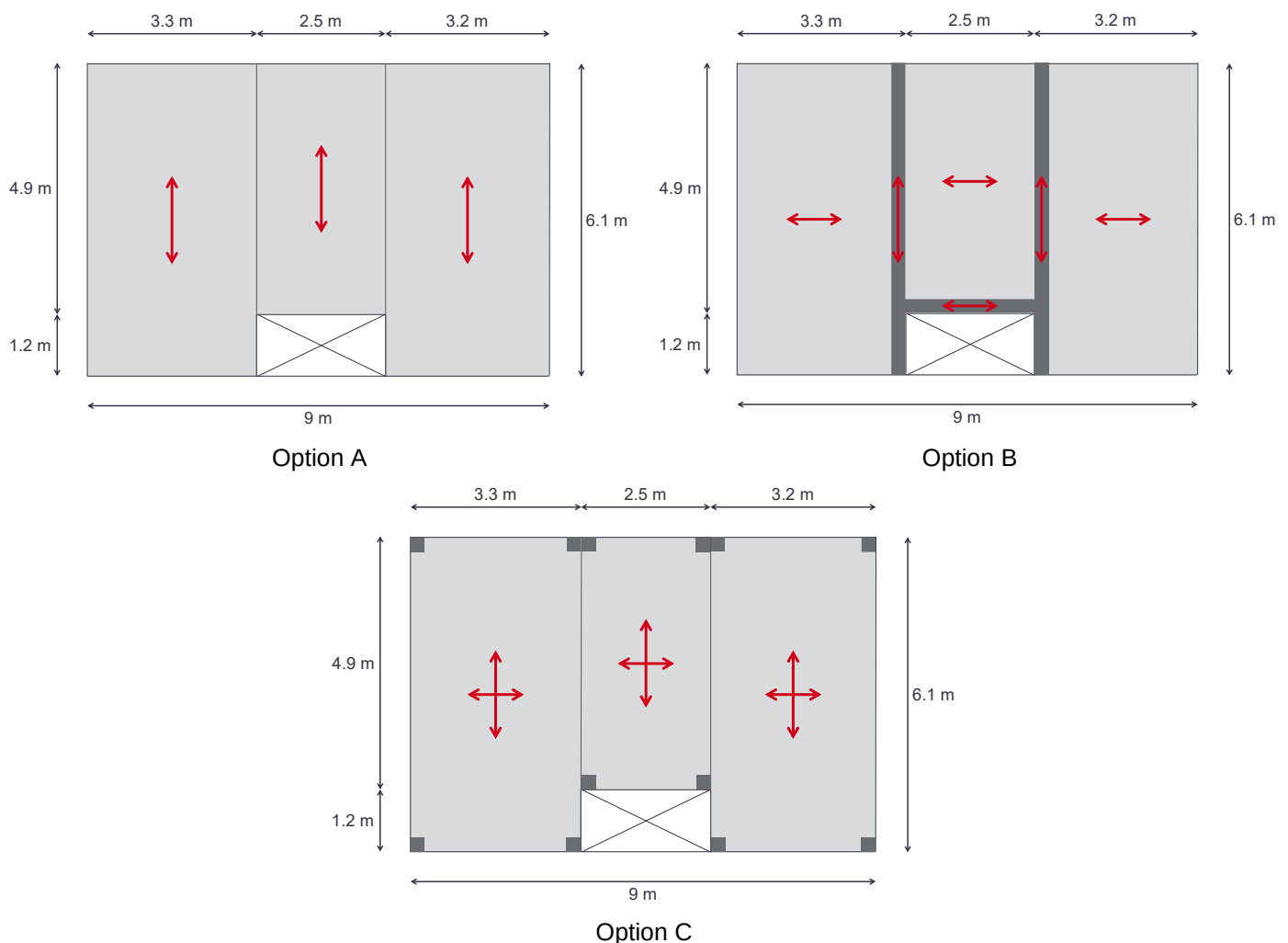


Figure 60: Options for span directions

### 9.2.3 Floor type

In Chapter 6, groove floors, hollow space floors, and floors with separated building services were identified as the three categories of flexible floor systems. In the evaluation of the circularity and flexibility of the different existing floor systems, especially the floors from the latter two categories scored high. The floor designs from the first category scored lower due to less independence between the load-bearing floor and the building services.

For a complete separation between the load-bearing floor and the building services, as with the suspended ceiling and raised floor system, essentially two systems are needed. One system is required for the structural function of the floor and another for the housing of the building services. This leads to an increase in the total height of the floor system and the costs needed to cover both systems. Because the hollow space floors also score good on flexibility and allow for the incorporation of the building services within the structural height of the floor, it is decided to base the new design on this floor type.

Based on the hollow space floor concept, the floor design consists of a slab with ribs and panels to cover the openings between the ribs. These openings can be at the top or at the bottom of the floor, as illustrated in Figure 61. The ducts and pipes can be laid between the ribs freely. To allow for reconfiguration of the pipes, openings need to be made in the ribs. To limit the number of additional production operations and the resulting costs, these openings should be in fixed locations depending on the forces in the ribs.

Because of the openings that need to be made in the ribs, the two-way span concept of option C from Figure 60 is less suitable. The two-way span utilises ribs in both directions, as illustrated in Figure 61. As a result, the reconfigurability of the building services is limited and many more openings need to be made than in a one-way slab, driving up the costs. Therefore, option C is not further considered.

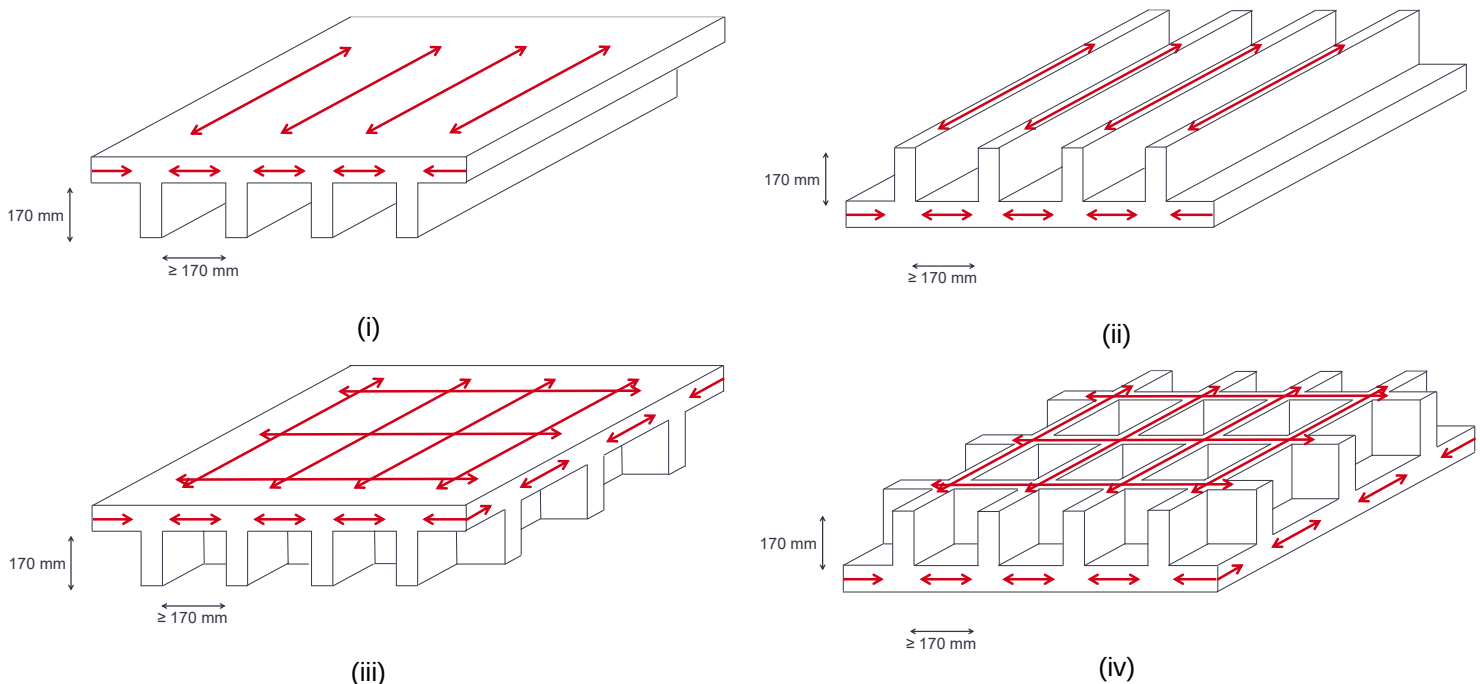


Figure 61: Floor design concepts for a one-way span with accessibility on top (i) and at the bottom (ii) and for a two-way slab with accessibility on top (iii) and at the bottom (iv)

Besides the structurally required dimensions, the height of the ribs and the space between the ribs are dependent on the space required by the building services. In the current design, the building services take up a height of up to 168 mm. This height includes the intersection of services. The building services that require the largest space are ventilation and sewerage, with a diameter of up to 125 mm (Dreßen, 2011). Therefore, the openings in the ribs should have a minimum diameter of 125 mm. The ribs themselves must of course be of a larger height to facilitate these openings, but also to allow for enough

height for the insulation and the intersection of building services. To allow for the intersection of most services, a height of approximately 170 mm is required (Dreßen, 2011). The space between the ribs should preferably be larger than this height, to allow for easier routing and reconfiguration.

Accessibility from the bottom, as is the case with the design concepts at the left side of Figure 61, has the advantage that the panels that cover the space between the ribs do not have to be load-bearing. In addition, no furniture or heavy objects are placed on top of the removable panels that could limit the accessibility. The downside is that working above one's head to adapt or reconfigure the building services is quite uncomfortable. When the building services are accessible from the top, they are much easier to work on. As a result of gravity, it is also easier to add additional mass, for example using gravel, to the floor system to increase the sound insulation properties when the opening is situated at the top. Structural considerations also play a role in the choice between an opening at the top or at the bottom. These considerations are discussed later on.

#### 9.2.4 Materials

The materials that are taken into consideration for the floor design are timber, concrete, and steel. To simplify the production process and curtail the production costs, it is preferable to limit the combination of elements from different materials. Taking into consideration the efficiency of the production and construction process, the use of concrete is preferable. With the use of concrete, the load-bearing floor can be made out of one element, reducing the need for additional operations for connections between elements. This production efficiency is also well suited to the desired industrialised production process. Therefore, the floor system will be designed in concrete.

For the shorter span direction of option B from Figure 60, a material choice also needs to be made for the beams that carry the floor elements. Here, the height of the beam is of interest. To limit the total floor height, the additional height as a result of the beam should be minimal. Figure 62 gives an initial estimation for the required height for a span of 6.1 m, using beams of different materials based on the applicable rules of thumb for a simply supported beam (Braam & Lagendijk, 2011; Soons et al., 2016). From Figure 62 it becomes apparent that the steel beams with an H-section, hollow section, or THQ-section require the least amount of height for the span. Therefore, these are the sections that are taken into consideration for the design of the beams.

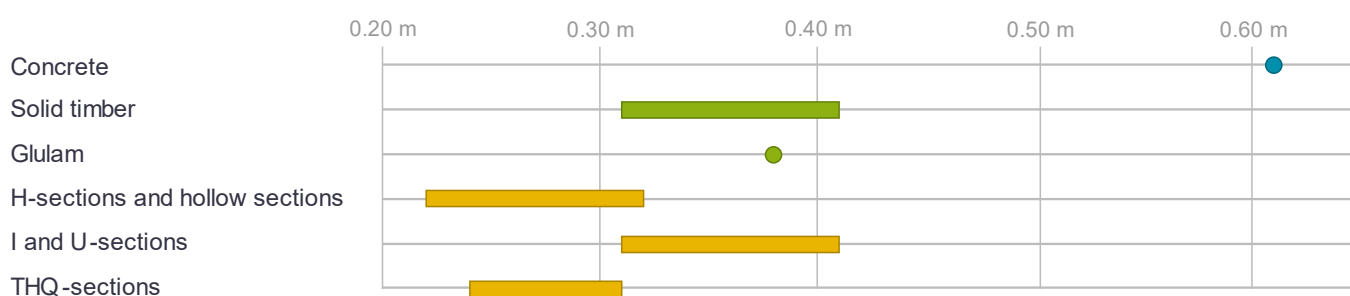


Figure 62: Required beam height based on rules of thumb for simply supported beams (Braam & Lagendijk, 2011; Soons et al., 2016)

#### 9.2.5 Structural design

The structural design is done based on the properties given in Table 30. Examples of the structural calculations can be found in Appendix J. In these structural calculations, the different design concepts are designed and checked on bending moment resistance and shear force resistance in the ultimate limit state and crack control and deflection control in the serviceability limit state.

Table 30: Material design properties

|                          |                              |
|--------------------------|------------------------------|
| <b>Concrete strength</b> | C30/37                       |
| <b>Reinforcement</b>     | B500 B                       |
| <b>Exposure class</b>    | XC1 (minimum coverage 15 mm) |

In addition to the structural design of the floor element in the longitudinal and transversal direction, the possibility for the openings in the ribs, required for routing and reconfiguration of building services, is also assessed. For the structural evaluation of the rib openings, a reduced rib height is assumed at the location of the openings, as illustrated on the left side of Figure 63. As indicated in Chapter 9.2.3, the openings should have a minimum diameter of 125 mm. The height of the rib at the openings is taken as the remaining height from the top or bottom of the opening to the slab. The reduction of the cross-sectional height also reduces the bending moment resistance and shear force resistance of the cross-section. Because the reduced shear force resistance is more easily compensated through an increase in shear force reinforcement, the bending moment resistance is governing in the location of the rib openings. Therefore, the rib openings are located at the ends of the ribs, where the acting bending moments are the lowest. It is calculated until what distance from the end of the rib, the remaining cross-section would be able to take the acting bending moment to establish the possible width of the rib openings in the different design concepts. The shear force resistance at the openings is also verified.

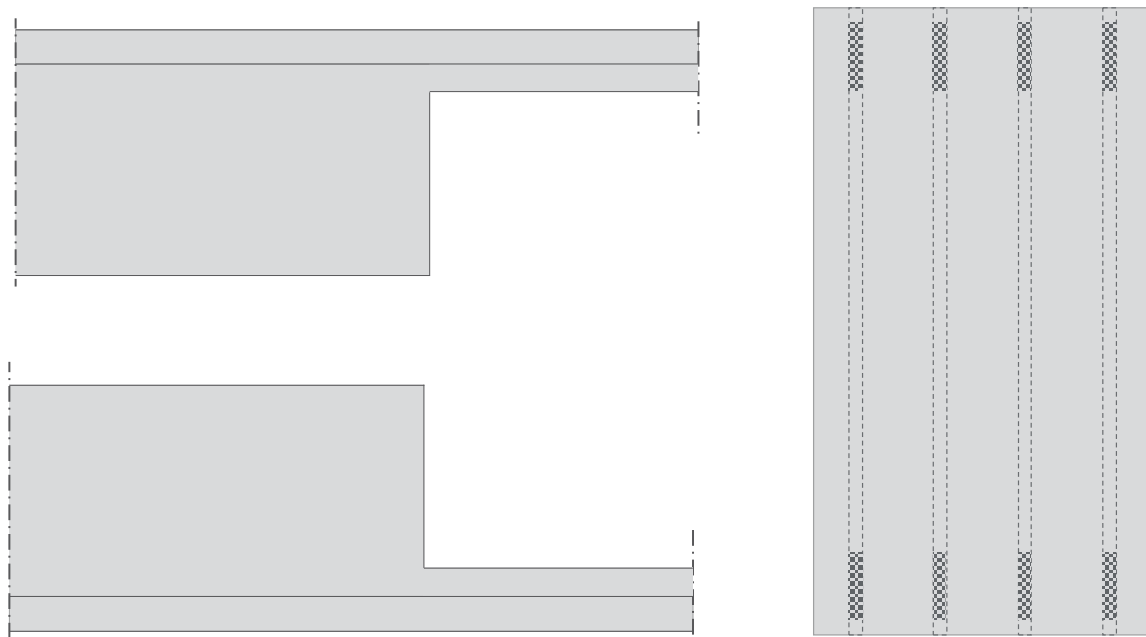


Figure 63: Schematisation of rib openings: side view with opening at the bottom (top left) side view with opening at the top (bottom left), and top view (right)

Table 31 gives an overview of the loads that are taken into consideration for the structural design of the floor system. The loads are applied to the floor in the combination of actions for persistent situations for the ultimate limit state calculations and in the frequent combination of actions for the serviceability limit state calculations. As mentioned in Chapter 9.1.1, the Dutch Building Decree also dictates that a floor should be able to take the load combination of actions for accidental design situations. This accidental load concerns the impact of a vehicle and should be placed on the structure horizontally (Nederlands Normalisatie-instituut, 2016). The magnitude of this load is dependent on the proximity of the building to certain categories of traffic. Because the location of the building is unknown and because the focus of the structural design is initially on the vertical loading, the combination of actions for accidental design situations is not included in the calculations.

Table 31: Loads for structural design

| Permanent loads                           |                       |          |                   |
|-------------------------------------------|-----------------------|----------|-------------------|
| Slab                                      | $g_{\text{slab}}$     | Variable | kN/m <sup>2</sup> |
| Rib                                       | $g_{\text{rib}}$      | Variable | kN/m <sup>2</sup> |
| Cover panels                              | $g_{\text{panel}}$    | 0.25     | kN/m <sup>2</sup> |
| Building services                         | $g_{\text{services}}$ | 0.25     | kN/m <sup>2</sup> |
| Variable loads                            |                       |          |                   |
| Variable floor load residential buildings | $q_{\text{res}}$      | 1.75     | kN/m <sup>2</sup> |
| Movable partitions                        | $q_{\text{part}}$     | 0.8      | kN/m <sup>2</sup> |

#### 9.2.5.1 Option A: Structural design of the floor with a long span

Figure 46 gives a schematisation of the design concepts for Option A. On the left, the cross-sectional views for the options with the ribs on the top and on the bottom are shown and on the right, a top view is given.

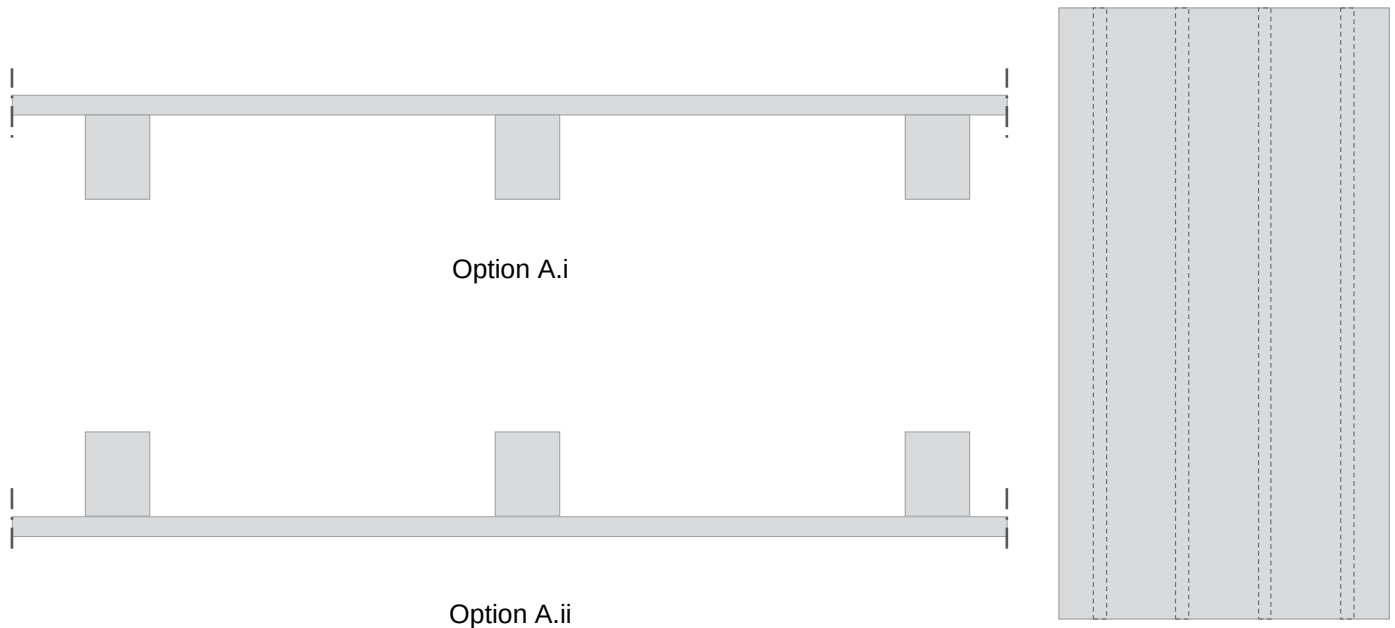


Figure 64: Schematisation of Option A: cross-sectional view (left) and top view (right)

Calculations for option A.i, a floor spanning the full length with accessibility from the bottom, can be found in Appendix K.1. These calculations have been done for a floor system with 3, 4, and 5 ribs. Only the calculations of the system with 4 ribs are given in the appendix, the other calculations follow the same method. In the structural design, the aim was to limit the total height of the systems and the amount of material used in order to reduce the overall costs. Table 32 gives an overview of the total height and material use of the full span floor system with openings on the bottom with either 3, 4, or 5 ribs. Also, the maximum distance from the end of the ribs for the placement of the rib openings is given.

As can be seen in Table 32, the three designs with different numbers of ribs all have the same height. For the height, the requirements for the rib height given in Chapter 9.2.3 and the required reinforcement diameters and concrete coverage are governing. The distances from the end of the beam where the openings can be located are also within the same order of magnitude for the three options. For the option with three ribs, a larger rib width is applied than for the option with 4 and 5 ribs as a result of the spacing requirements for the longitudinal reinforcement. The ribs are 100 mm wide in the design for 4 and 5 ribs



and are 126 mm wide in the design for 3 ribs. Even though the latter system requires wider ribs, it is still the most material-efficient option. Therefore, the system with 3 ribs is preferable.

Table 32: Comparison of different number of ribs for option A.i

| Number of ribs | Total height | Total volume of concrete | Distance from the end of the beam where the opening can be located |
|----------------|--------------|--------------------------|--------------------------------------------------------------------|
| 3              | 208 mm       | 1.16 m <sup>3</sup>      | 350 mm                                                             |
| 4              | 208 mm       | 1.18 m <sup>3</sup>      | 320 mm                                                             |
| 5              | 208 mm       | 1.28 m <sup>3</sup>      | 370 mm                                                             |

The calculations for Option A.ii, with accessibility from the bottom and three ribs, can be found in Appendix K.2. Table 33 gives the resulting height, material use, and distance for rib openings. The design with accessibility from the top requires ribs with a width of 326 mm in order to facilitate rib openings up to 133 mm from the end of the span. In this case, the ribs are over twice as wide as for the option with accessibility from the top and provide a space for the openings that is only marginally wider than the minimum requirement of 125 mm. The width required for the frame of the openings has not been subtracted from this distance yet, leaving even less space for the rib opening. As a result of the wider ribs, the design also has a larger self-weight.

The design for option A.ii does have a smaller total height than the designs for option A.i. Because the required reinforcement area can be distributed over the width of the entire flange of the rib rather than the width of the rib alone, a smaller diameter of longitudinal reinforcement can be used. As a result, this diameter is no longer governing for the minimum concrete cover and the nominal concrete cover has a lower value, resulting in a lower total floor height.

Table 33: Comparison of different number of ribs for option A.ii

| Number of ribs | Total height | Total volume of concrete | Distance from the end of the beam where the opening can be located |
|----------------|--------------|--------------------------|--------------------------------------------------------------------|
| 3              | 206 mm       | 1.74 m <sup>3</sup>      | 133 mm                                                             |

To limit the increase in height and material use for Option A.ii, the possibility of prestressing is investigated. Through the application of prestressing, the bending stiffness of the structure can be increased which could reduce the need for additional material in the ribs (Braam, 2015). The prestressing is applied using pretensioned steel, as this form of prestressing is especially well suited to the industrialised production process (Braam, 2015; Walraven & Braam, 2019). For prefabricated structural elements using pretensioned steel, a draped tendon is complicated to achieve (Braam, 2015). Straight prestressing tendons are also more practical for the applicable cross-section of the rib. Draped tendons are positioned higher in the cross-section near the supports. Because the cross-section in the design contains openings near the supports, the cross-section has a smaller height at this location, complicating the course of curved tendons. Therefore, the application of straight prestressing tendons is more also more practical.

In the case of full prestressing, no tensile stresses occur in the cross-section (Walraven & Braam, 2019). To achieve this, the anchorage of the tendons should be placed within the kern area of the cross-section (Braam, 2015; Walraven & Braam, 2019). The kern areas of both the full cross-section and the cross-section at the rib openings are calculated in Appendix K.3.3. The kern areas of both cross-sections do not overlap, complicating the application of full prestressing. Therefore, partial prestressing is applied. Some tensile stress is allowed to occur in partially prestressed elements. In this case, regular reinforcement and prestressing tendons are combined to control crack width and deformation. Appendix K.3 contains the preliminary design calculations for the partial prestressing of Option A.ii (Walraven & Braam, 2019). Table 34 gives the resulting system height, material use, and distance for rib openings.

As can be seen in Table 34, the design with partial prestressing requires less material use than the other designs. A smaller rib width of 100 mm can be used compared to the design for option A.ii without prestressing. As a result of the smaller ribs in combination with the smaller total height, compared to the

designs for option A.i, an overall reduction of material use is achieved. Based on the results in Table 32 till Table 34, the design option with partial prestressing is preferable. However, it is possible that the increased complexity of the production process of prestressed elements negates these advantages. Whether the reduction in height and material use outweigh the possible increase in production costs should be investigated further in order to decide on the preferred design option.

Table 34: Comparison of different number of ribs for option A.ii with partial prestressing

| Number of ribs  | Total height | Total volume of concrete | Distance from the end of the beam where the opening can be located |
|-----------------|--------------|--------------------------|--------------------------------------------------------------------|
| 3 - prestressed | 206 mm       | 1.04 m <sup>3</sup>      | 232 mm                                                             |

#### 9.2.5.2 Option B: Structural design of the floor with a short span

Figure 65 gives a schematisation of the design concepts for Option B, with the cross-sectional views for both options of the placement of the ribs on the left and the top view on the right.

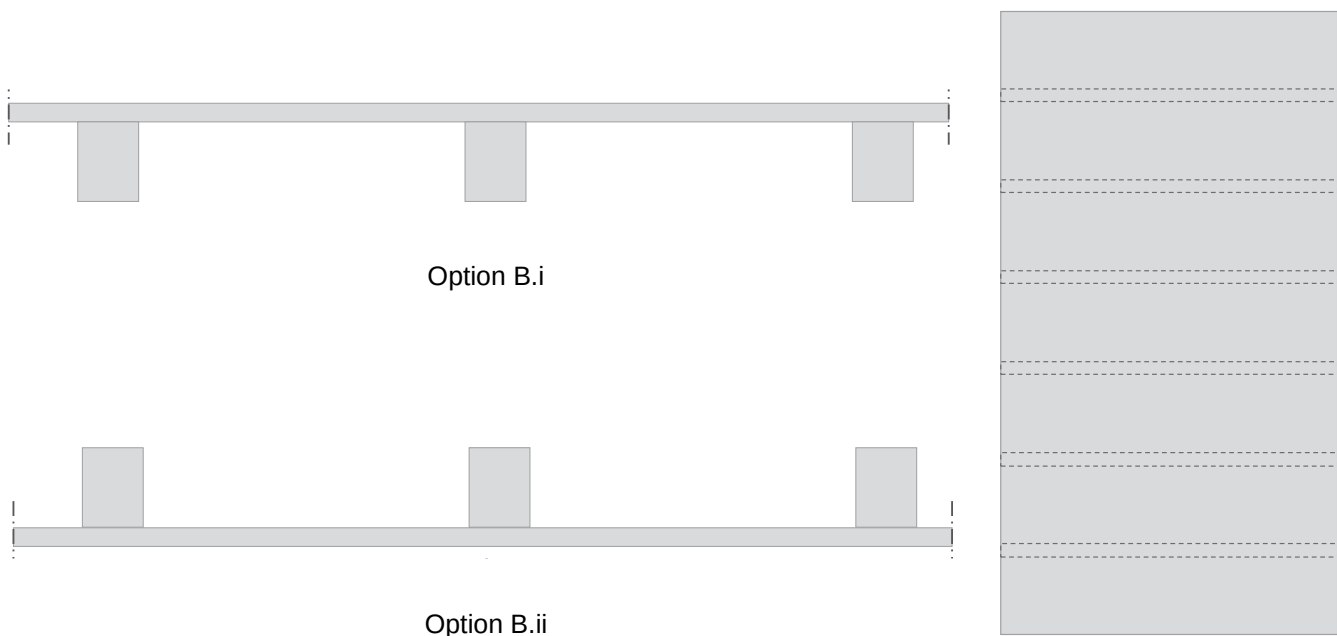


Figure 65: Schematisation of Option B: cross-sectional view (left) and top view (right)

The calculations for option B.i, floor elements spanning a shorter distance from beam to beam with accessibility from the bottom, can be found in Appendix K.4. These calculations have been done for floor systems with 6, 7, and 8 ribs. Table 36 gives an overview of the total height of the floors, material use, and distance for rib openings.

The floors systems shown in Table 36 have a smaller height than the floor systems with a larger span without prestressing and the same height as the prestressed design for option A.ii. This reduction in height is possible because a smaller reinforcement diameter can be used in the slab. The ribs of the three design options in Table 36 all have the same width. Consequently, the use of fewer ribs results in lower material use. With the exception of the prestressed design, the design options for B.i have a lower material use than the designs for option A. Compared to the other designs, barring option A.ii without prestressing, the distance available for the placement of openings in the ribs is limited for the design with 6 ribs. The space available is enough to meet the minimum requirement of 125 mm. However, in some cases, it could be preferable to have more space available. This could be considered based on the building services required and possible reconfigurations expected on a project basis. It is also possible to increase the width of the ribs slightly to improve the amount of space available for the rib openings. For incremental increases of the rib width, it is expected that the material use for the design with 6 ribs

remains the lowest. It should be noted that the material use in Table 36 only includes the concrete floor elements and does not include the beams required to carry the floor elements.

For the height considerations of the floor design, it is of importance that the beam does not significantly increase the total height of the floor system. Appendix K.4.9 contains calculations to check whether it is possible to carry the floor elements and the own weight of the beam with a profile that is of the same or a smaller height than the concrete floor element. The calculations show that an RHS profile with a height of either 200 or 180 mm is capable of carrying the applicable loads. The load-bearing capacity of these beams is checked on bending moment resistance, shear resistance, and deflection. As a result, it can be concluded that the use of a beam to carry the floor element does not need to increase the total floor height. The calculations to check the possibility of using steel beams within the floor height of the concrete floor elements is the full extent to which the use of the beams is worked out. The connection and load transfer between the concrete floor elements and the beam are not further elaborated on.

Table 35: Comparison of different number of ribs for option B.i

| Number of ribs | Total height | Total volume of concrete | Distance from the end of the beam where the opening can be located |
|----------------|--------------|--------------------------|--------------------------------------------------------------------|
| 6              | 204 mm       | 1.02 m <sup>3</sup>      | 190 mm                                                             |
| 7              | 204 mm       | 1.08 m <sup>3</sup>      | 220 mm                                                             |
| 8              | 204 mm       | 1.13 m <sup>3</sup>      | 250 mm                                                             |

Option B.ii, with 7 ribs and accessibility from the top, is designed both without and with prestressing. The calculations for these designs can be found in Appendix K.5 and Appendix K.6 respectively. The results are presented in Table 36. For both designs, there is an increase in the material use compared to the design with 7 ribs for option B.i. The design with prestressing has a larger total height than the other designs for option B because the prestressing tendons are placed in the area of the slab that acts as the flange or the rib. Therefore, the diameter of the prestressing steel is included in the minimum height calculation of the slab, resulting in a higher slab and a larger total floor height. The design with prestressing has slightly more space available for the rib openings than the other designs for option B. The minimal space available for the rib openings in the design without prestressing is the same as for Option A.ii without prestressing.

Table 36: Comparison of different number of ribs for option B.ii

| Number of ribs  | Total height | Total volume of concrete | Distance from the end of the beam where the opening can be located |
|-----------------|--------------|--------------------------|--------------------------------------------------------------------|
| 7               | 204          | 1.14 m <sup>3</sup>      | 133                                                                |
| 7 - prestressed | 206          | 1.12 m <sup>3</sup>      | 294                                                                |

### 9.2.5.3 Overcapacity

The floors with a high flexibility score in Chapter 8.2.2 also score high on overcapacity. Both the load-bearing overcapacity and building services overcapacity are part of the structural design. In the structural design of the different floor concepts, the overcapacity of the floors is initially not taken into consideration. Therefore, the overcapacity of the designs, for which the properties are given in Table 32 to Table 36, is calculated by applying different combinations of variable loads and surplus space for buildings services. Based on the scoring system given in

Table 26 of Chapter 7.2.3, the different design options are scored on their overcapacity. For the variable loads, the load ranges indicated in Table 25b are applied. The percentage ranges for surplus space for building services in Table 25a are applied to the width available for the openings in the ribs. The percentage of overcapacity is calculated compared to the minimum opening requirement of 125 mm. On top of the minimum opening and the percentage of overcapacity, an additional margin of 15 mm is added to take into account the frame of the opening. As a result, the minimum distance from the end of the beam where the openings can be located is 140 mm. The space between the ribs is not the focus in the

calculation of the building services overcapacity, as the space between the ribs provides over 50% surplus space in all design options.

Table 37 gives the resulting overcapacity scores for the different floor design options. The designs for Option A.ii and B.ii without prestressing are not included in this table because the span available for the openings in these designs do not meet the minimum requirements. For the designs of option A, the overcapacity score is limited by the maximum shear resistance at the openings in the rib. The overcapacity score for the Option B designs is limited by the maximum bending moment resistance at the openings in the ribs. For most designs, the overcapacity score is limited by the load-bearing overcapacity, with the exception of design option B.i with 6 ribs, where the span available for openings also forms a restriction. In some cases, a higher overcapacity score can be achieved by adding slightly more reinforcement or pressing steel, as indicated in the remarks column of Table 37. If no other changes are required and these changes do not affect the total floor height or material use of the design concept, the improved overcapacity score is also included in Table 37. For the design concepts of Option B, a load-bearing overcapacity in the category high of Table 25b affects the requirements for the steel beam. It is verified that the load-bearing capacity of the steel beam can sufficiently be increased by using a profile with a larger thickness or width. It is not necessary to use a profile with a larger height, as a result, the total floor height is not affected.

Table 37: Overcapacity scores for design concepts

| Number of ribs            | Overcapacity score |   | Remarks                                                                                            |
|---------------------------|--------------------|---|----------------------------------------------------------------------------------------------------|
| Option A.i                |                    |   |                                                                                                    |
| 3                         | 3                  |   |                                                                                                    |
| 4                         | 3                  |   |                                                                                                    |
| 5                         | 3                  |   |                                                                                                    |
| Option A.ii - prestressed |                    |   |                                                                                                    |
| 3                         | 3                  | 4 | A score of 4 can be achieved by adding one extra prestressing tendon (no other changes)            |
| Option B.i                |                    |   |                                                                                                    |
| 6                         | 3                  |   |                                                                                                    |
| 7                         | 3                  | 4 | A score of 4 can be achieved by adding one extra longitudinal reinforcement bar (no other changes) |
| 8                         | 3                  | 4 | A score of 4 can be achieved by adding one extra longitudinal reinforcement bar (no other changes) |
| Option B.ii - prestressed |                    |   |                                                                                                    |
| 7                         | 4                  |   |                                                                                                    |

### 9.2.6 Building physics

Besides the considerations with regard to structural design, building physics topics also affect the design of a floor system. In Chapter 9.1 it was determined that the building codes include requirements concerning acoustics and fire safety. The design options presented as a result of the structural design in Chapter 9.2.5 are evaluated on their acoustic and fire safety properties. Based on this evaluation, the designs are adapted to ensure they comply with the applicable requirements.

#### 9.2.6.1 Acoustics

The Dutch Building Decree prescribes the methods required to determine whether a floor element complies with the sound insulation requirements. For both the air sound and contact sound insulation, these methods require a physical testing and measuring set-up (Nederlands Normalisatie-instituut,

2019e). Because it is not possible to perform the measurements within the scope of this research, the evaluation of the sound insulation of the floor designs is based on more general properties of the designs.

The requirements concerning acoustics for housing with a single residential function are not too stringent. Traditional floor systems usually provide sufficient insulation without the need for additional acoustic insulation measures (van der Linden et al., 2013). For floor elements of houses with a single residential function, it can be assumed that a mass of 250 to 300 kg/m<sup>2</sup> provides sufficient sound insulation (Bouwman, 2021). With the use of a concrete floor, this mass can be translated to a floor thickness of 0.1 to 0.12 m. At the ribs, the floor designs have a larger thickness than this and thus sufficient mass. However, between the ribs, the slab height is much smaller. For the different floor designs, the floor slab between the ribs has a mass between 85 and 95 kg/m<sup>2</sup>, which is insufficient to meet the requirements for sound insulation.

The sound insulation of the floor designs can be improved by increasing the mass of the floor (van der Linden et al., 2013). This can be achieved by increasing the height of the floor slab. However, increasing the height of the floor slab would also increase the overall system height of the floor, which is not preferable.

Mass can also be added in other ways, for example by adding a loose gravel or aggregate material in the spaces between the ribs. Because this is a loose material, the building services between the ribs are not fixed in place and can still be accessed and reconfigured. Due to gravity, such a loose material is less practical for application in the floor designs with accessibility from the bottom, as the removal of an accessibility panel would cause the material to fall out. Because the added material is merely used as ballast, it does not have to be a high-grade material and it is possible to use recycled aggregate material that comes from demolition waste. Based on a recycled granulate material with a dry density of at least 2100 kg/m<sup>3</sup>, a layer of 76 mm would be required for sufficient sound insulation for the floor designs with accessibility from the top (Twee “R” Recycling Groep B.V., n.d.). This leaves enough space for the most common building services diameter. Where building services with a larger diameter are placed or where the intersection of piping takes place, locally not enough mass can be added for sufficient sound insulation. The effect of the lack of sound insulation in these spots on the overall sound insulation should be further investigated.

As a result of the additional mass, the load-bearing capacity of the floor designs should be re-evaluated. For the prestressed design for option A.ii, 5 more prestressing tendons and an extra longitudinal reinforcement bar are required to carry the additional load. With this additional prestressing, an overcapacity score of 1 is achieved. The addition of another two prestressing tendons increases the overcapacity score to 3 and another three added tendons allow for an overcapacity score of 4. The addition of the extra prestressing tendons is possible within the requirements for the minimum spacing of prestressed steel tendons (Nederlands Normalisatie-instituut, 2011a). The prestressed design for option B.ii requires no extra prestressing tendons to carry the additional permanent load and scores a 4 on overcapacity.

Another option is to design the space between the ribs as a cavity structure. A structure with two layers and air in between can achieve a large degree of sound insulation for a relatively low mass, as is illustrated in Figure 66 (van der Linden et al., 2013). This is due to the lack of direct transmission of vibrations from one layer to the other. A cavity structure works as a mass-spring system, where the two layers are the masses that can exert a vibration on the intervening air layer, the spring (van der Linden et al., 2013). The calculations for a mass-spring system are more intricate than for a solid structure and are not part of this thesis.

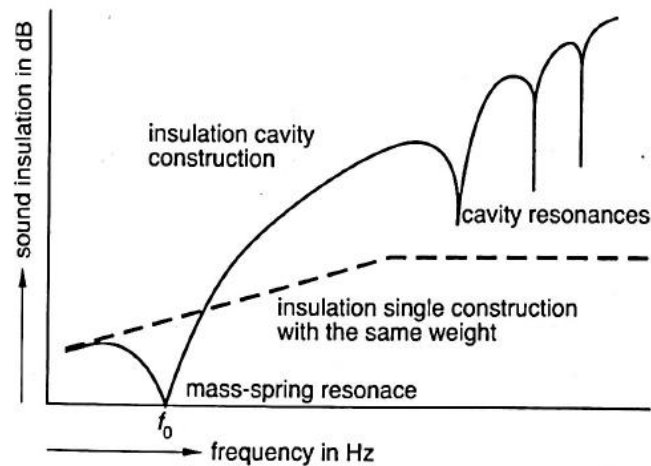


Figure 66: General insulation curve of a cavity structure (van der Linden et al., 2013)

Finally, it should be noted that the acoustic properties of a floor element are also dependent on the detailing of the connections to the rest of the structure. These connections are not worked out in this thesis and therefore their effect on the acoustic properties is not further discussed.

#### 9.2.6.2 Fire safety

The assessment of the fire safety of the floor designs is based on the requirement of 60 minutes of fire resistance. As discussed in Chapter 9.1, this degree of fire resistance allows for use of the floor elements at any location within most ground-level residential buildings. The fire resistance is the time during which a building element exposed to fire can remain in function (Breunese & Maljaars, 2015). A distinction can be made between two types of fire resistance. The first type regards the fire resistance in terms of load-bearing capacity. The second type concerns the fire separating function, which involves the barrier function of a building element to the spread of smoke and fire (Breunese & Maljaars, 2015). The calculations for the fire resistance of a structure in terms of the fire separating function are complicated and hardly addressed in the Eurocodes. In addition, for structures with both a load-bearing and fire separating function, such as floors, the load-bearing function is often governing (Breunese & Maljaars, 2015). Therefore, the fire safety design of the floor concepts is limited to fire resistance in terms of the load-bearing capacity.

The tabulated data prescribes a minimum slab height for different degrees of fire resistance. For a fire resistance of 60 minutes, a slab height of 80 mm is given. This would require the doubling of the slab height that has been used thus far. As the height is an important characteristic of the floor design and the tabulated data is based on generalised parameters, a reduced cross-section calculation is done to investigate if a smaller slab height would also suffice. The zone method, given in Appendix B.2 of the Eurocode, is applied for the calculation of the reduced cross-section as this is the method recommended or use with smaller or slender sections (Nederlands Normalisatie-instituut, 2011b). Using this method, the cross-section affected by fire is represented by a reduced cross-section from which the damaged zone  $a_z$  is subtracted. This is illustrated in Figure 67. Using the reduced cross-section and strength properties, the load-bearing capacity under fire conditions is calculated and verified. The calculations can be found in Appendix L.



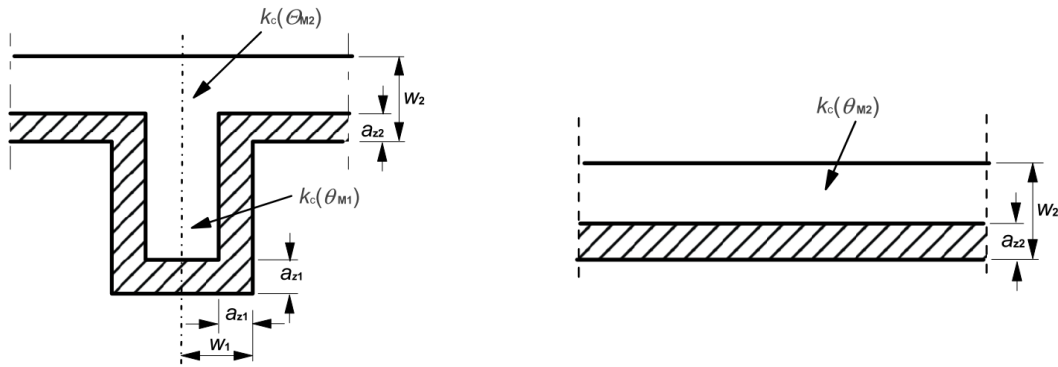


Figure 67: Reduced cross-section of (a) a beam and (b) a slab (Nederlands Normalisatie-instituut, 2011b)

The curves given in Appendix B.2 of the Eurocode for use in the zone method are applicable for a  $w$ -value of at least 50 mm. For the width of the ribs, this is in line with the dimensions that are used thus far. For the slab, this does mean an increase in height, although a smaller increase than for the height required based on the tabulated data. The load-bearing capacity for the prestressed designs for both option A.ii and option B.ii are designed and calculated, using the minimum  $w$ -value of 50 mm. Based on this input, the designs for option A.ii and option B.ii have sufficient load-bearing capacity for a fire situation during 60 minutes. Only the shear force capacity in the interface between the flange and the web is inadequate for both designs. The shear force resistance in this interface can be improved by adding transverse shear reinforcement or by locally increasing the height of the slab. With the improvement of the shear force resistance in the interface between the flange and the web, both designs provide sufficient load-bearing resistance for a fire during 60 minutes.

It should be noted that in the verification of the slab in transversal direction, the effects of prestressing applied in the longitudinal direction are not taken into account. The effects of the ballast added for sound insulation and the building services within the floor structure on the behaviour of the system in a fire situation are also not taken into consideration. Finally, the possibility of spalling is also not addressed in the calculations, as spalling is unlikely to occur in members designed for exposure class X0 and XC1 due to the low moisture content (Nederlands Normalisatie-instituut, 2011b).

The design for option B.ii also includes a steel beam. Steel is an excellent heat conductor and is usually applied in relatively thin-walled and lightweight members. As a result, steel members heat up relatively quickly when exposed to fire, which coincides with a relatively quick deterioration of the strength properties of the material. The calculations of the remaining bending moment resistance of the steel beam exposed to fire in Appendix L.2.7 shows that the steel beam is no longer capable of taking the applied bending moment after 60 minutes of fire exposure. As an increase in the dimensions of the steel beam is not desirable with regard to the total floor height, different solutions should be utilised. The fire resistance of the beam could be improved through the application of insulation, such as foam, blankets, intumescent paints or gypsum boards (Breunese & Maljaars, 2015). These solutions are also beneficial to the insulation and radiation properties of the beam, relevant for the fire separating function of the floor.

### 9.2.7 Cover panels

As a result of the acoustic requirements in combination with the desire for a low system height, the prestressed designs for options A.ii and B.ii are the remaining suitable designs. Both designs have accessibility to the building services from the top. The spaces between the ribs that allow for the accessibility of the building services need to be covered to provide an even surface for the use of the space on top. As a cover, the use of panels is preferable over a cast floor or a floor made out of a few larger elements to allow for removability of the coverage and with that the accessibility of the space between the ribs. Because the panels are placed at the top side of the floor, the panels need to be able to bear the variable load from the use of the space on top and be able to transfer this load to the load-bearing concrete floor below. The material choice, load-bearing capacity and the connection details of the panels are not worked in this report. However, a number of considerations and possibilities are discussed.

As mentioned, the panels should be removable to allow for accessibility of the space between the ribs. To facilitate the removability of the panels, it is preferable if the panels can be detached through a non-damaging operation, like removing a screw, or no operation at all. The panels only need to vertically transfer the load on top to the structure below. As the panels are not part of the structural system of the building, no other loads or stresses need to be transferred through the connection of the panels. Because the panels are placed on top of the floor element, gravity can ensure the vertical load transfer and no screws or other added elements are required to keep the panels in place vertically.

To prevent shifting of panels and any resulting damage to the panels, it is practical to have a connection that keeps the panels in place horizontally. To keep the panels easily removable, this should be a dry connection. There are different ways in which such a connection could be designed. Magnets could be used so that the panels snap back into place. Another option is the use of a click system, where the two connective pieces each have a geometry that click into each other to form a connection. For example, a system similar to a click laminate can be used or a connection with a hook and an eye that catch onto each other. A third option is the use of corner elements with edges that keep the panels in place. These could be made of a rubber or silicone-type material on the edges and the bottom that prevents the slipping of the panels through friction. These are a couple of examples of possible connection systems but not an exhaustive list of options. Any connection system chosen should be checked if they provide enough horizontal resistance to prevent slipping of panels in normal use

For the material choice, it is of importance that the panel can span the distance between two ribs with a minimal height. For design option A.ii the distance between two ribs is 1000 mm and for design option B.ii this distance is 771 mm. The material choice also affects the circularity assessment of the floor system. In the circularity assessment of the existing floor designs in Chapter 8.2.1, it was shown that the use of panels with a low degree of reusability negatively affected the MCI of the HOLCON floor. Therefore, it is preferable if the material has a high degree of reusability. The use of recycled materials can also positively influence the circularity of the floor system. In one of the interviews from Chapter 5.2, it was also mentioned that if a good looking material is used for the panels or the top layer of the panels, no additional top floor is necessary. This saves materials and extra height and is also beneficial for the accessibility, as no extra layer needs to be removed. Possible materials that could be used are flax panels, solid timber or glue laminated timber, cement or stone tiles, chipboard, calcium sulphate panels, and steel elements. If the material itself is not strong enough to cover the span between the ribs, a light aluminium or steel frame could be added as support.

### 9.2.8 Verification of requirements

In Chapter 9.1, the relevant requirements for the design of floor systems were compiled. These requirements include requirements based on the applicable building codes and the desires and demands of the stakeholders. The compiled requirements formed the basis on which the different design choices were made. The building code requirements include the load-bearing capacity, acoustic properties, and fire safety of the floor design. These requirements are discussed, included and verified in the design stages of Chapters 9.2.5 and 9.2.6.

The financial aspect of the design is an important part of the stakeholder requirements. This includes the total floor height and the ease of production and construction of the floor system. The height of the floor system is one of the leading criteria for the design choices made in Chapters 9.2.5 and 9.2.6 and is thus adequately included in the design. The ease of production and its effect on the costs of the floor system were also taken into consideration. The number of openings that need to be made in the ribs is part of the considerations in the choice of a floor type. And for the material choice, the ease of industrialised production and a minimal amount of additional operations in production are taken into account. The ease of construction largely depends on the connection used to integrate the floor system with the rest of the structure. As the connections details are not worked out, no conclusive verdict can be given on the ease of construction of these elements.

Finally, the living comfort and ease of maintenance, upgradability, and durability are of importance to the end-user. The ease of maintenance and upgradability is part of the flexibility objective of the design. This flexibility is ensured through the implementation of the space between the ribs and the accessibility of this space. Through the application of removable coverage panels, the accessibility can be ensured. The use of concrete provides adequate durability of the structural floor element. The comfort of living and the

durability of the top floor depend on the choice of covering panels. These panels should be durable and stay in place under normal use and should provide a level top surface.

### **9.3 Final designs**

*Combining the consideration for span direction, floor type, material choice and the requirements for structural design, acoustics, and fire safety, there are two remaining feasible design options. These are the prestressed designs for option A.ii and option B.ii. The properties of the design for option A.ii are given in Table 38. This design has three prestressed ribs over the longer direction of the floor and has accessibility from the top, a schematisation of the design is given in Figure 68.*

*Table 39 and Figure 69 give the properties and schematisation of the design for option B.ii. This design has seven prestressed ribs over the shorter direction of the floor. The floor element is carried by a beam that spans in the longer direction, the properties of this beam are not included in*

Table 39.

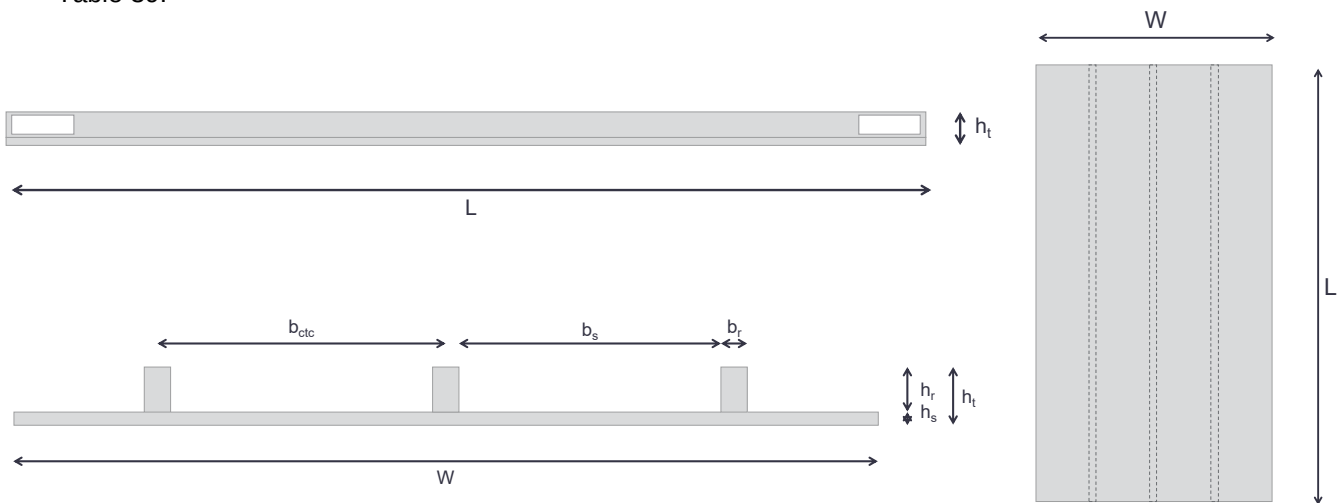


Figure 68: Schematisation Properties of the design for option A.ii

Table 38: Properties of the design for option A.ii

| Dimensions                             |           |        |    |
|----------------------------------------|-----------|--------|----|
| Span                                   | L         | 6100   | mm |
| Width                                  | W         | 3300   | mm |
| Number of ribs                         | n         | 3      |    |
|                                        |           |        |    |
| Slab height                            | $h_s$     | 50     | mm |
| Rib height                             | $h_r$     | 170    | mm |
| Total height                           | $h_t$     | 220    | mm |
| Rib height at opening                  | $h_{r,o}$ | 22.5   | mm |
|                                        |           |        |    |
| Width rib                              | $b_r$     | 100    | mm |
| Space between ribs                     | $b_s$     | 1000   | mm |
| Centre to centre distance between ribs | $b_{ctc}$ | 1100   | mm |
|                                        |           |        |    |
| Material properties                    |           |        |    |
| Concrete                               |           | C30/37 |    |
| Reinforcement steel                    |           | B500 B |    |
| Prestressing steel                     |           | Y1670C |    |
|                                        |           |        |    |
| Reinforcement                          |           |        |    |
| Longitudinal reinforcement (per rib)   |           | 5Ø6    |    |

|                                                                    |  |      |                   |
|--------------------------------------------------------------------|--|------|-------------------|
| Transversal reinforcement, top (per 1 m)                           |  | 12Ø4 |                   |
| Transversal reinforcement, bottom (per 1 m)                        |  | 7Ø4  |                   |
| Transversal shear reinforcement (per rib)                          |  | 1Ø2  |                   |
| Prestressing (per rib)                                             |  | 24Ø8 |                   |
| <b>Other properties</b>                                            |  |      |                   |
| Total volume of concrete                                           |  | 1.32 | m <sup>3</sup>    |
| Own weight                                                         |  | 303  | kg/m <sup>2</sup> |
| Overcapacity score                                                 |  | 4    |                   |
| Distance from the end of the beam where the opening can be located |  | 411  | mm                |

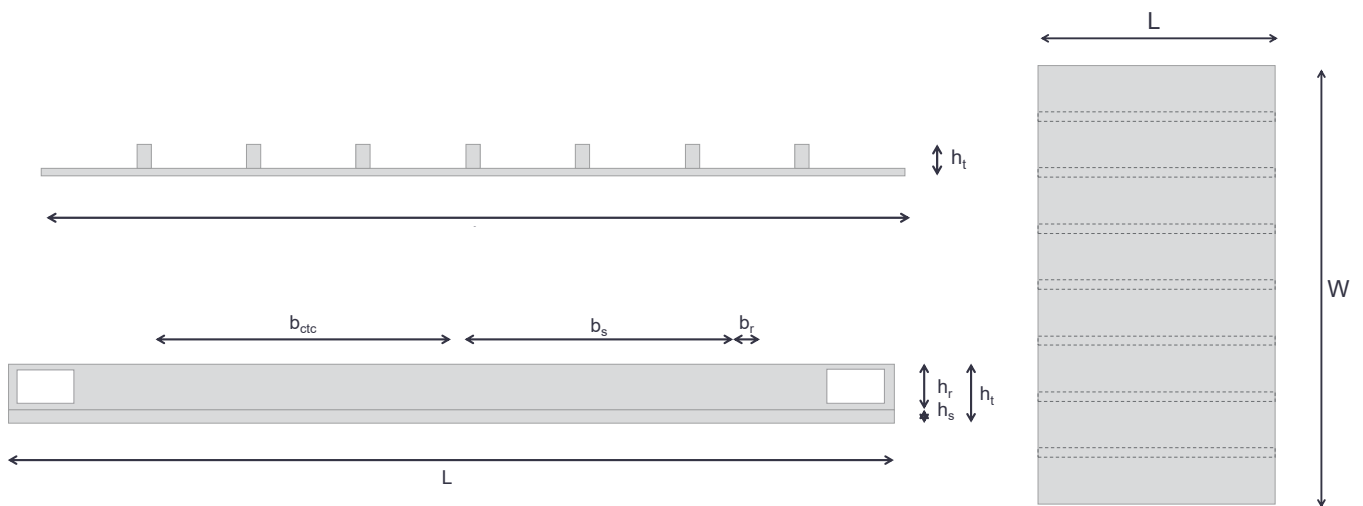


Figure 69: Schematisation Properties of the design for option B.ii



Table 39: Properties of the prestressed design for option B.ii

| Dimensions                                                         |           |        |                   |
|--------------------------------------------------------------------|-----------|--------|-------------------|
| Span                                                               | L         | 3300   | mm                |
| Width                                                              | W         | 6100   | mm                |
| Number of ribs                                                     | n         | 7      |                   |
|                                                                    |           |        |                   |
| Slab height                                                        | $h_s$     | 50     | mm                |
| Rib height                                                         | $h_r$     | 170    | mm                |
| Total height                                                       | $h_t$     | 220    | mm                |
| Rib height at opening                                              | $h_{r,o}$ | 22.5   | mm                |
|                                                                    |           |        |                   |
| Width rib                                                          | $b_r$     | 100    | mm                |
| Space between ribs                                                 | $b_s$     | 771    | mm                |
| Centre to centre distance between ribs                             | $b_{ctc}$ | 871    | mm                |
|                                                                    |           |        |                   |
| Material properties                                                |           |        |                   |
| Concrete                                                           |           | C30/37 |                   |
| Reinforcement steel                                                |           | B500 B |                   |
| Prestressing steel                                                 |           | Y1770C |                   |
|                                                                    |           |        |                   |
| Reinforcement                                                      |           |        |                   |
| Longitudinal reinforcement (per rib)                               |           | 12Ø4   |                   |
| Transversal reinforcement, top (per 1 m)                           |           | 7Ø4    |                   |
| Transversal reinforcement, bottom (per 1 m)                        |           | 7Ø4    |                   |
| Transversal shear reinforcement (per rib)                          |           | 1Ø2    |                   |
| Prestressing (per rib)                                             |           | 9Ø6    |                   |
|                                                                    |           |        |                   |
| Other properties                                                   |           |        |                   |
| Total volume of concrete                                           |           | 1.40   | m <sup>3</sup>    |
| Own weight                                                         |           | 310    | kg/m <sup>2</sup> |
| Overcapacity score                                                 |           | 4      |                   |
| Distance from the end of the beam where the opening can be located |           | 212    | mm                |

## 10 Evaluation of new design

### 10.1 Evaluation of flexibility measures

The designs that result from the design process in Chapter 9 are evaluated and compared to the current design, the traditional floor systems, and the existing flexible floor designs. This evaluation and comparison are done based on the weight-to-height ratio of the floor systems, the circularity and flexibility scores, and a qualitative assessment of the design aspects that influence the costs of the floor.

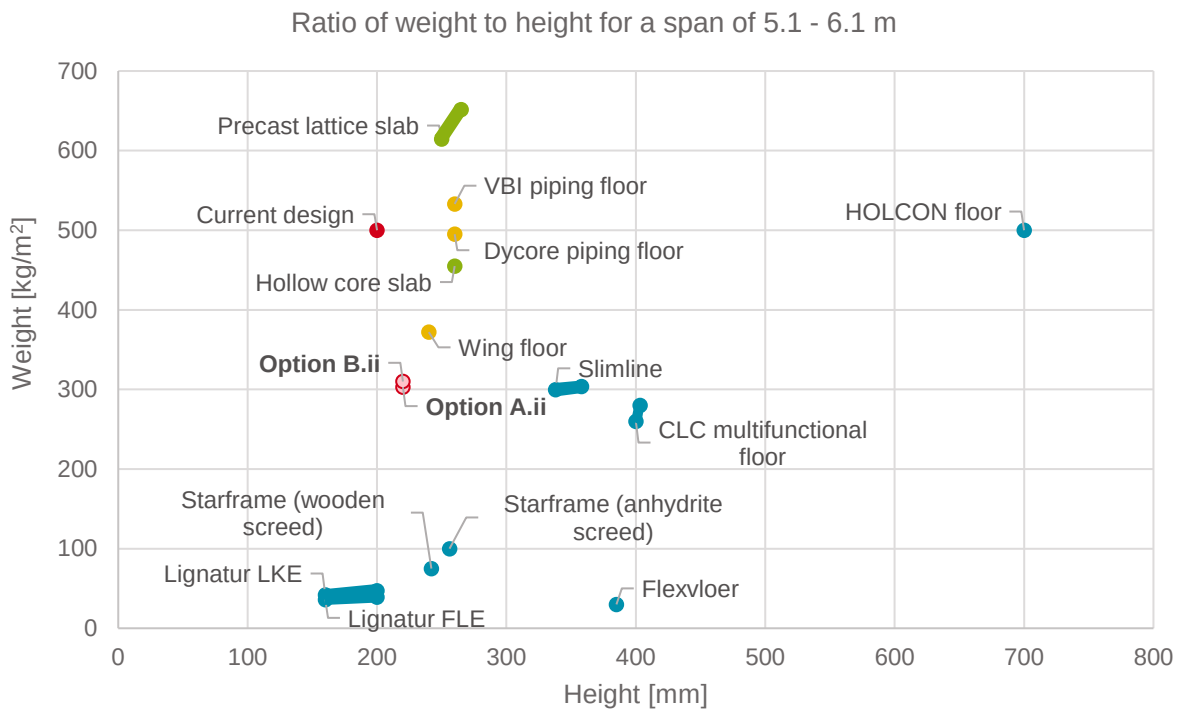


Figure 70: Weight-to-height ratio for a span of 5.1 to 6.1 m including new designs

In Figure 70, the designs for options A.ii and B.ii are added to the weight-to-height ratio graph of Figure 53. The weight and height for both designs are very similar. The graph shows that the design concepts have a slightly larger height than the current floor design. But they have a lower height for all other floor systems, with the exception of the timber Lignatur floors. The height of the design concepts is the result of the height required for the incorporation of the building services and the slab height required for fire safety. When looking at the weight of the floor in Figure 70, the design concepts are placed in the middle ground. They have a lower weight than the current design, the traditional floor systems, and the groove floors and are within the same weight range as the steel-concrete composite hollow space floors. The design concepts are significantly heavier than the existing flexible floor designs made of steel and timber. The weight of the design concepts in Figure 70 includes the granulate used as ballast for the acoustic properties but does not include the steel beam for design option B.ii.

### 10.1.1 Circularity assessment

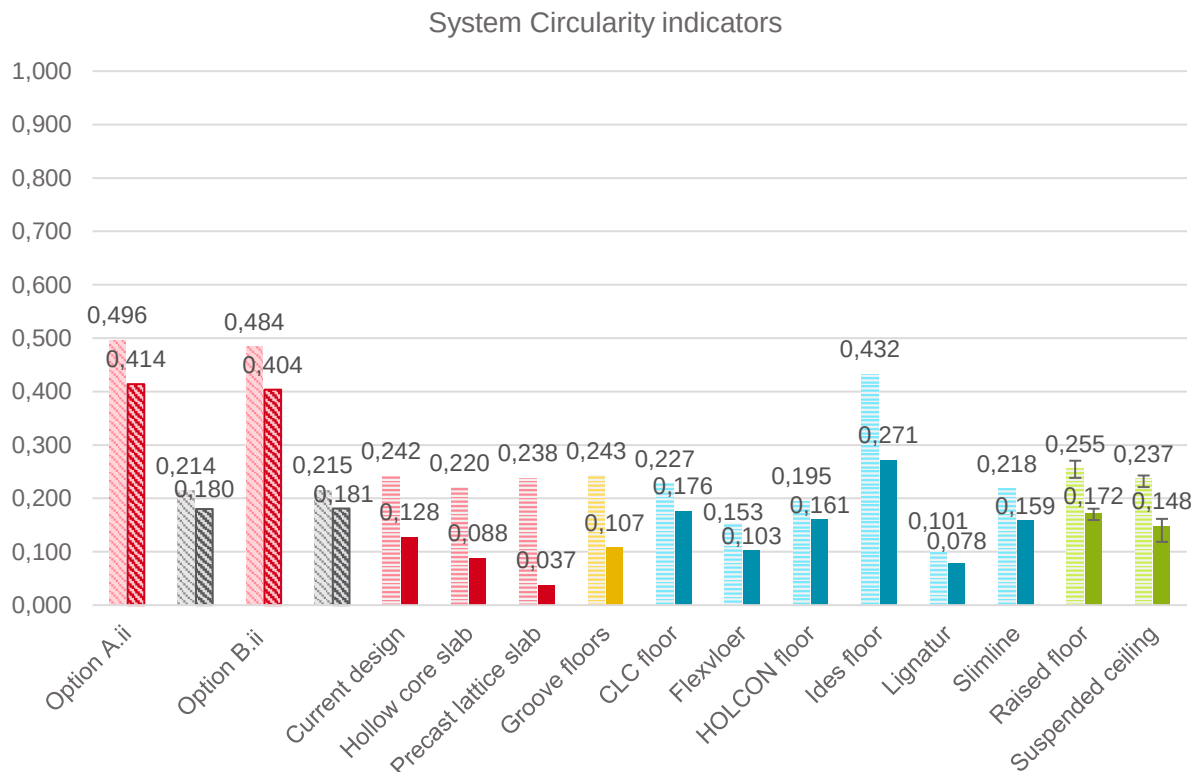


Figure 71: Comparison of circularity scores, each floor gives a theoretical value (left) and a practical value (right) including new designs

In Figure 71, the circularity assessment of the design concepts are included in the overview of the system circularity indicators given in Figure 55 of Chapter 8.2.1. The full assessment of the design concepts can be found in Appendix M.1. In the assessment, where information is required on the connection of the design concepts, a similar connection system as for the current design is assumed. The material properties used for the cover panels in the circularity assessment are based on a comparison of the values from the NIBE (2019) database for the different material options mentioned in Chapter 9.2.7.

Most notable from the graph in Figure 71, is that the theoretical SCI values for the design concepts are very high compared to the other floor designs. This is caused by a high MCI, as a result of the use of recycled granulate as a ballast material. Because of this material choice, a relatively large percentage of the total weight has non-virgin material input, which is beneficial for the MCI. None of the other floors included in Figure 71 has any percentage of non-virgin material input. To illustrate the effect of the non-virgin material input, the SCI values for the design concepts with a virgin material input for the granulate material are also included in Figure 71, these values are shown in grey. The choice to use a loose granulate material was made to be able to add weight in the space between the ribs, without fixing the building services in place. The opportunity to increase the MCI through the use of recycled materials is an added advantage because the material does not need to be intact or of a high grade in order to fulfil its function.

Without the use of a recycled granulate material, the theoretical SCI value is much lower. The theoretical SCI value is slightly lower than for the current design, the traditional floors systems, and the steel-concrete composite hollow space floors. According to NIBE (2019), the granulate material provides less reusable output than the reinforced concrete used in the aforementioned floor systems, bringing down the overall MCI and theoretical SCI values slightly. When a recycled granulate material is used, this reduction of the MCI value is more than compensated. It is noticeable that even though the practical SCI score of the design concepts is lower than for the current design, traditional floor systems, and steel-concrete composite hollow space floors, their practical SCI value is higher. For all disassembly factors, the design concepts score either the same or higher than the previously mentioned floor systems. As the disassembly factors that regard the connection details are taken from the current design, the difference

comes primarily from the disassembly factors of functional separation, functional independence, and technical life cycle coordination. Even without the inclusion of the non-virgin material input of the recycled granulate material, the practical SCI value of the design concepts is second best behind the Ides floor.

### 10.1.2 Flexibility assessment

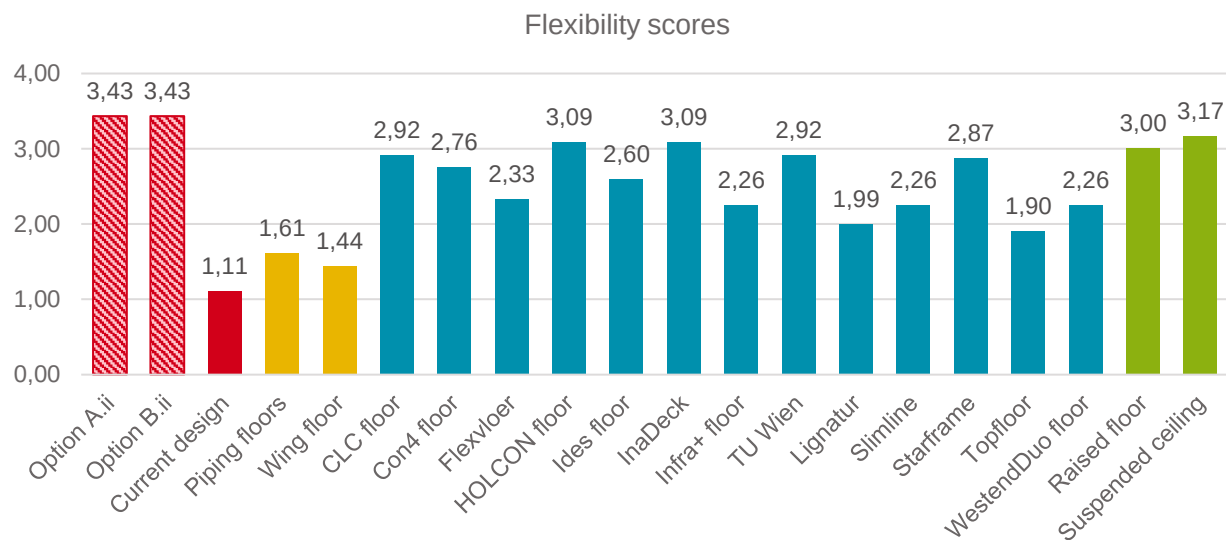


Figure 72: Comparison of flexibility scores including new designs

In Figure 72, the flexibility scores of the design for options A.ii and B.ii are included in Figure 56 of Chapter 8.2.2. Both designs have the same flexibility score, the full flexibility assessment can be found in Appendix M.2. Figure 72 shows that the design concepts have the highest flexibility score of all the floor systems included in the comparison. Their flexibility score is even higher than for the suspended ceilings system. The design concepts score higher than the suspended ceiling system on durability, interface simplicity and standardisation. The difference in durability score is because a lower than average durability score is applied for the suspended ceiling system as it is not part of the load-bearing system and is thus assumed to be less robust. For the high score on interface simplicity of the design concepts, it is assumed that dry connections are used for the coverage panels, as proposed in Chapter 9.2.7. Finally, the design concepts score better on standardisation than the suspended ceiling system, as the design concepts consist of a single system rather than the combination of two separate systems for the structural function and the coverage of the building services. The only flexibility characteristic that the suspended ceiling system scores higher on than the proposed design concepts is the characteristic of independence. This is a result of the design choice to integrate the building services within the structural height of the floor to limit the total system height. Compared to the other high scoring flexible floor designs of the HOLCON floor and the InaDeck, the design concepts score higher on accessibility and interface simplicity. Both scores are related to the choice of connection of the cover panels, for which the use of a dry connection system that requires no additional operations for accessibility is proposed in Chapter 9.2.7.

### 10.1.3 Evaluation

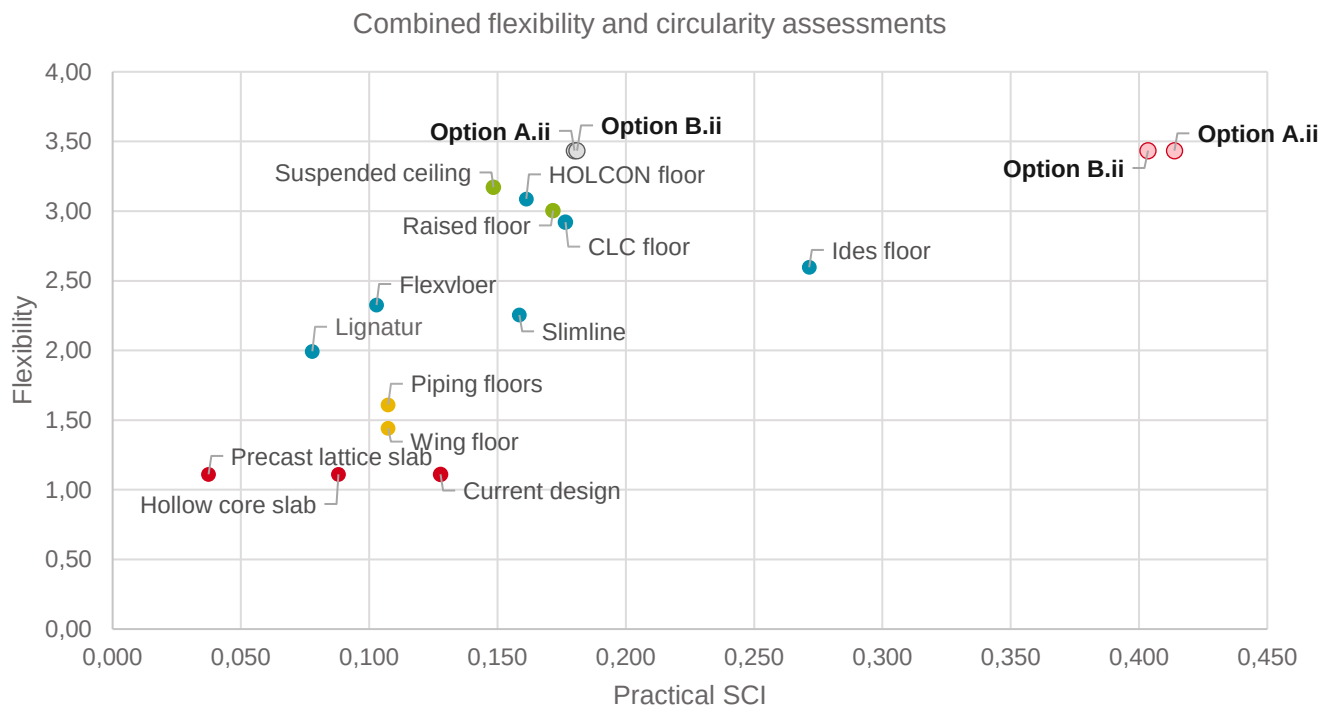


Figure 73: Combined circularity and flexibility assessments including new designs

Figure 73 is the adaptation of Figure 58 from Chapter 8.2.3 to include the flexibility and circularity scores of the design concepts for options A.ii and B.ii. For both design options, the practical SCI values with recycled and non-recycled granulate material are included, shown in pink and grey respectively. Figure 73 clearly shows that even with the use of non-recycled granulate material, the design concepts score on the high end of both flexibility and circularity compared to the other floor systems. Appendix M.3 shows that there is a significant positive correlation between the circularity and flexibility scores of the floor systems included in the comparison.

Table 40: Multicriteria comparison of important design factors for different floor systems

|                      | Height | Circularity | Flexibility | Cost influencing factors |
|----------------------|--------|-------------|-------------|--------------------------|
| Option A.ii          | +      | +           | +           | +/-                      |
| Option B.ii          | +      | +           | +           | +/-                      |
| Current design       | +      | +/-         | -           | +                        |
| Hollow core slab     | +      | -           | -           | +                        |
| Precast lattice slab | +      | -           | -           | +/-                      |
| Piping floors        | +      | +/-         | -           | +                        |
| HOLCON floor         | -      | +           | +           | -                        |
| Slimline floor       | +/-    | +           | +/-         | +/-                      |
| Raised floor         | -      | +           | +           | -                        |
| Suspended ceiling    | -      | +           | +           | +/-                      |

Table 40 shows a multicriteria comparison of a number of different floor systems based on the most important design factors. The design factors included are the total height of the floor systems, their circularity and flexibility scores, and their cost influencing factors. The assigned indicators in Table 40 are based on the evaluations in this chapter and the evaluation of the cost influencing factors in Chapter 6.4. As the cost influencing factors only concern the factors that influence the costs of the floor system itself, the design factor of height is included separately because this factor especially affects the costs of the rest of the structure. The comparison only includes the floor systems for which information is available on all four design factors.

For the current design, a positive cost indicator is assumed, as cost efficiency is one of the prerequisites of this design. The design concepts for options A.ii and B.ii are assigned a medium indicator for the cost influencing factors. This is based on several considerations. First of all, the material efficiency of the designs, as evident by their relatively low weight in Figure 70, positively affects the costs of the design. On the other hand, the use of prestressing is assumed to require a more complex production process than the use of regular reinforced concrete, negatively affecting the costs. In addition, the openings that need to be made add to the number of operations required in the production process. For the design for option B.ii, the use of a steel beam also negatively impact the costs, as it requires extra operations during construction and increases the total material use. However, in comparison to the cost influencing factors of the other floor designs, the effect of the steel beam on the costs influencing factors is not expected to be large enough to warrant a negative indicator in Table 40.

On all the other design factors, the design concepts for option A.ii and option B.ii score positive indicators. This results in an overall better score for these designs than for the other floor systems included in the comparison.

## 10.2 Effect on the building

Changes to a part of the structure are likely to have an effect on the rest of the building structure. Therefore, the properties of the design concept that are different from the current floor design are discussed to evaluate the effect of these differences on the structure and circularity of the rest of the building.

The only differences between the proposed design concepts and current design that are likely to effectively influence the rest of the building design are the height and the weight of the floor system. The height of the design concepts is not much larger than for the current design, but there is still an increase in the total floor height. This larger height results in an increase in the amount of façade surface area and changes to the design of the staircase. As the difference in height is only 20 mm, it is not expected that this will significantly affect the overall costs of the building. The weight of the proposed design concepts is significantly lower than for the current floor design. As a result, the supporting structure has to bear a smaller load and a more material-efficient version of the supporting structure might be able to be implemented. Less material use in the rest of the structure could positively influence the overall costs of the project. If the new floor system is to be implemented in an existing building design, the costs for the design, calculation, and drawing work required for the adaptation of the initial design should also be taken into consideration.

The design concepts score well on circularity and provide an improvement of the circularity in comparison to almost all of the other floor designs discussed. As a result, the proposed floor designs are likely to positively influence the overall circularity of the building. The increase in floor height is marginal, therefore it is not expected that a significant addition of materials in other parts of the building is required. As a result, the effects of the additional material use on the circularity of the building are likely to remain minimal. As a result of the lower weight of the design concepts, a reduction in material use in the rest of the building might even be possible, which would positively influence the circularity of the building. Overall, the application of the proposed floor designs would likely positively influence the general circularity of the building. Besides the material use and the circularity of the building element itself, the application of the proposed floor system also incorporates the circular design strategy of flexible design into the building. Through the flexible design of the floor systems, longer use of the building and the floor elements is facilitated by allowing for and simplifying the adaptation of the building services incorporated in the floor to changing requirements and circumstances. This way, the flexible design of the floor system contributes to the overall circularity of the building design.



# Part IV: Conclusion

## 11 Discussion

To determine the effectiveness of flexibility measures regarding the integration of the building services and load-bearing function in improving the circularity of prefabricated floor systems in residential buildings, several steps have been taken. Research has been done into the characteristics and impact of flexible design, multiple existing traditional and flexible floor systems have been assessed on their flexibility and circularity, and a case study has been done on the design of a new flexible floor system. In this chapter, first, the interpretations and implications of the results are discussed, then the limitations of the study are addressed.

### 11.1 Interpretation and implications

The results of the literature study into the factors that influence flexible design show that there are many indicators of flexible design. More careful analysis and structuring of these indicators reveal that certain indicators form the basis of flexible design. These indicators are identified as the technical characteristics of flexibility that need to be incorporated in a design to realise the other indicators of flexible design. The analysis of the indicators of flexible design and the identification of the technical characteristics of flexible design contribute to a clearer understanding of what flexible design is and how it can be implemented.

The exploration of existing flexible floor designs reveals that already multi designs for different versions of flexible floor systems have been made. An analysis of these floor designs helps identify how the different technical characteristics of flexible design can be implemented in a floor design. However, the existing flexible floor designs are either not widely used in the building industry, specifically not widely used in the residential building industry, or have a limited degree of flexibility. The existing flexible floor systems are also not specifically designed for application in residential buildings. An evaluation of the existing flexible floor designs and a comparison with traditionally used floor systems shows that many of the flexible floor systems have a larger total floor height than the traditional floor systems. From the interviews with people from different disciplines related to the building industry, it became apparent that the building industry is often hesitant to adopt new developments due to the financial risk involved with working with unfamiliar systems and the slim profit margins of the industry. As a result of the slim profit margins, the costs of a building system are an important factor in whether a new system will successfully be adopted by the building industry. One of the factors that influence the costs of a building project is the height of a floor. The conservative and frugal nature of the building industry explains why the existing flexible floor designs, using novel systems and a larger total height, have not been able to widely catch on in the building industry.

Aside from the challenges, there are also opportunities for the implementation of flexible floor systems. Clients and investors are increasingly interested in sustainable and circular alternatives. When it can be shown that flexible floor systems are actually more circular than traditional floor systems, they can provide a good sustainable alternative. Whether there is a connection between the flexibility and circularity of floor systems is the subject of this research. Another opportunity for clients and investors is the adaptability of flexible floor systems to changing circumstances and requirements. Professional investors are most likely to recognise and value these opportunities. Flexible design also offers opportunities to the building industry itself. If building parts from different disciplines are designed flexibly without fixed integration, the different disciplines can also do their work independently without having to take each other's work into account. In addition, flexible design offers opportunities for the reduction of failure costs and an increase in the standardisation of building elements. So, if the challenges of the conservative nature of the building industry can be overcome and a design can be made that limits the additional costs of a flexible floor system, there are sufficient opportunities to put the flexible design of floor systems into practice.

Based on a literature study, various circularity and flexibility assessment methods were identified. However, few of the existing assessment methods are applicable to building components. This shows that there is still room for improvement and development of the assessment and quantification of both circularity and flexibility. Quantification provides the designers with guidance to include circularity and flexibility in their work. For the circularity assessment, the BCI method is chosen based on availability and applicability for building components. The focus of this circularity assessment method is on the circular reuse of materials and the disassembly potential of components. The circularity assessment method under development by Platform CB'23 has a wider approach to circularity, including the

environmental impact of the production and the use of building parts. Therefore, the use of this assessment method could have provided a more complete perspective on the circularity of the different floor systems. On the other hand, the application of the Platform CB'23 assessment method would have required more time and more detailed information, which was not always available. Nevertheless, as the Platform CB'23 method was not yet fully developed at the time of writing this thesis, the application of this method was not possible. For the assessment of the flexibility of the floor systems, no suitable methods were available at all. To fill this void, a flexible assessment method for floor elements was developed based on the technical characteristics of flexible design identified in this research. The focus of this flexibility assessment method is on the combination of the building services and load-bearing function of the floor elements. As this is the first version of such an assessment method, it could benefit from further development.

Two comparable designs emerged from the design process for a new flexible floor system. Both systems are prestressed and have accessibility from the top. All initial design options were developed, verified, adapted, and sometimes discarded based on the compiled building code and stakeholder requirements. Not all of the relevant building code requirements were included in the design process. Advanced calculations or test setups are outside the scope of this research and were therefore not included. The design option where the floor elements span the shorter direction and a beam spans the longer direction does not result in a smaller total floor height, as was the initial design intention. This design does result in more material use, both in the concrete floor element and through the application of a beam. As a result, the prestressed design option with floor elements that span the longer direction is more suitable for application in practice.

The comparison of the weight-to-height ratio of the developed design concepts and the existing floor systems shows that the developed design concepts have a marginally larger height than the current floor design and a lower height than most of the other floor systems included in the comparison. This is preferential regarding the height limitations as a result of the stakeholders' wishes concerning the costs of the building project. In addition, the design concepts have a relatively small weight. As a result, the rest of the supporting structure could perhaps be designed more slender. In the design process, it became apparent that a much lower element weight is not practical for application in residential buildings as a result of the acoustic insulation requirements.

The circularity assessment of the developed design concepts shows that the use of non-virgin material input has a strong positive effect on the circularity score. Even without the inclusion of non-virgin material input, it is noticeable that the practical SCI scores, which include the disassembly factors, of the developed design concepts are higher than for most of the other floors. This can be traced back to the positive effect of the independence flexibility characteristic on the disassembly factors of functional separation, functional independence, and technical life cycle coordination. In the evaluation of the existing flexibility assessment methods in Chapter 7.2, it was already mentioned that the flexibility characteristic of independence is related to multiple design aspects relevant to disassembly potential. The developed design concepts have the highest flexibility score of all the floors included in the comparison. This high flexibility score is a result of the comparatively high scores on all characteristics of the flexibility assessment.

In the plotting of the circularity scores against the flexibility scores of the different floor designs in Figure 73, a positive correlation between the two scores becomes apparent. This is in line with the expectations, as flexible design is mentioned in literature as a circular design strategy. The correlation in the figure shows that floors with a higher degree of flexibility are generally also more circular. The circularity of the design concepts developed based on flexible design consideration supports this correlation, as for the design concepts with only virgin material use, no circular design considerations were included and a relatively high circularity score was still achieved. The only other design input for these floor designs are the cost considerations that form the framework for any practically feasible design to be used in the building industry.

## 11.2 Limitations

In the discussion of the limitations, the aspects of the research that impact the generalizability or practical applicability of the results are presented and reviewed.

The cost analysis of Chapter 6.4 is done based on available cost information taken from various sources. No actual cost calculations have been done as part of this research. As a result, the values used are merely indicative and can only be used for a qualitative, rather than a quantitative, analysis. In addition, because only floor systems for which cost information was readily available were included in the costs analysis, only the design characteristics of these floors were addressed in the analysis and the determination of the cost influencing factors. As the cost information was only readily available for a limited number of floor systems, the amount of design characteristics included in the analysis is also limited. Because costs play an important role in the building industry, a more in-depth cost analysis based on more different types of floor systems and more unambiguous cost information could provide a more complete insight into the cost influencing factors relevant for floor design.

The circularity and flexibility assessments of the existing flexible floor systems in Chapter 8.2, are based on the limited amount of information available on these floor systems. Consequently, the assessments include certain assumptions and the use of more generic material properties. As a result, the circularity and flexibility scores of these floor systems are not completely accurate. However, the accuracy of the scores is sufficient for the use as indicative values in the comparison of the different floor systems and to provide context for the current design and proposed design concepts. In the application of the circularity assessment method, the effect of flexible design on the length of the use phase is not included. This is because it is difficult to accurately quantify a representative change in the length of the use phase as a result of flexible design. Based on literature, it is expected that the service life of a building or building components is extended as a result of flexible design, which would positively influence the circularity score of the floor systems. As a result, the inclusion of flexibility in the length of the use phase for the circularity assessment method would amplify the positive correlation between flexibility and circularity and would thus not produce diverging results or a different conclusion.

There are several limitations to the design process in Chapter 9.2. Further elaboration and development on these limitations could affect the properties of the final designs. The limitations with regard to structural design encompass that the permanent load as a result of the cover panels is based on an assumption, that the structural design does not include any detailing or advanced calculations, that the effect of prestressing in the longitudinal direction on the load-bearing capacity in the transversal direction is not taken into account, that the horizontal stability of the floor design and the accidental load combination are not included in the structural design, and that no variation of the concrete properties or reinforcement steel properties is included in the design process. For prestressing, different steel classes are considered, but no other types of prestressing steel other than a wire are taken into account. There are also limitations regarding the building physics of the floor design that could affect the properties of the final design. In the verification of the fire safety, only the fire resistance with regard to the load-bearing capacity is included. The fire resistance regarding the separating function of the floor system is not verified, as these require more complicated calculations and/or a test setup. The elaboration on the sound insulation design is also limited. The use of a cavity structure for sound insulation could improve the feasibility of the design options without prestressing and with accessibility from the bottom. This is, however, not investigated in this research.

## 12 Conclusions

To answer the main research question, the answers to the 10 sub-question were gathered throughout the research. For the final conclusions, first, the answers to each sub-question are summarized. Then these conclusions are combined into the answer for the main research question.

### 12.1 Sub-questions

#### Theoretical framework

1. *How can flexible design be integrated in floor systems?*
  - a. *What design factors influence the flexibility of (building) products?*
  - b. *What are the opportunities and challenges for the implementation of flexibility measures in floor systems?*

The design factors that influence the flexibility of a product are accessibility, durability, independence, integration, interface simplicity, overcapacity, and standardisation. These are the factors that should be

included in a design process to accomplish flexibility of design. Accessibility concerns the possibility to access the components that need to be adapted without hindrance from other components. Durability regards the capacity of a material or system to continue to be useful after an extended period of time and usage. Independence indicates the technical separation of elements with different service lives and functions while integration regards the technical coupling of components that are unlikely to be ever adapted separately. Interface simplicity requires the use of uncomplicated mechanical connections between elements to allow for easy disconnection. Overcapacity indicates the capacity of a design to accommodate higher technical specifications than initially required and allows for flexibility in the application of the design in different functions with different technical requirements. Finally, standardisation regards the use of the same components size and construction details throughout the design.

The opportunities for the implementation of flexible design in building projects at the end of the client, lie predominantly in its appeal to professional investors. Professional investors are expected to have a better understanding than private homeowners of the value and the advantages of flexible floor design with regard to future developments and residual value. The growing interest in and increased willingness to invest in sustainable alternatives also provides an opportunity for flexible floor systems as a more circular alternative to regular floor designs. For the building industry itself, the opportunities of flexible design lie with the independence of the workflows of different disciplines, reduced failure costs, and the possibility to increase the standardisation of elements. The main challenges for the implementation of flexibility measures in floor systems are the conservative nature of the building industry and the expected increase of costs for both the floor element itself and possibly the rest of the building structure.

2. *To what extent are flexible floor systems for residential buildings already available on the market?*
  - a. *What solutions for flexible floor systems already exist?*
  - b. *How do the existing solutions for flexible floor systems include flexibility measures in their design?*
  - c. *What are the advantages and drawbacks of the existing solutions for flexible floor systems?*

Two different types of flexible floor systems exist. Those with the building services integrated within the structural height of the floor, and those that separate the structural floor from the building services. The former can be further divided into the categories of floors fitted with grooves for the routing of pipes and floors with a hollow space for the placement of building services. The other category consists of raised floor systems and suspended ceiling systems.

The common thread in the designs of the existing solutions for flexible floor systems is that the building services have their own place in the system. By avoiding the full integration of the building services and the load-bearing structure, an increase in the flexibility of the building services is achieved. The degree of independence between the building services and the load-bearing structure varies between the different existing solutions and types of floor systems. For the floors with the building services integrated within the structural height of the floor, the accessibility, and with that, the flexibility, of the building services is dependent on the removability of the applied screed. For the floor systems that separate the structural floor from the building services, the accessibility of the building services is typically guaranteed.

The main advantage of the flexible floor systems is the reconfigurability of the building services. For the hollow space floor, the raised floor system, and the suspended ceiling systems, the availability of space for reconfiguration is inherent to the design. To ensure reconfigurability in the groove floor systems, additional grooves have to be made during the production process. An important disadvantage of the existing flexible floor systems is that most of them have a larger height than the commonly applied floor systems, affecting the costs and the design of the rest of the building structure.

3. *How are the costs of a floor system influenced by the design?*
  - a. *What are the costs for the traditionally used floor systems and the existing flexible floor designs?*
  - b. *What design factors influence the costs of a floor system?*

Based on the comparison of the costs for different existing floor systems, the design factors that influence the costs of the floor element itself are the amount of material used, the need for individual operations and labour in the production process, and the combination of elements from different materials. It is possible that the latter two cost influencing factors are related. Besides the costs of the individual floor elements, the design of a floor system can also influence the overall costs of the building project through the time required for construction on site and the total height of the floor system.

4. *How can the effect of flexibility measures on the circularity of floor systems be assessed?*
  - a. *What methods exist to assess the circularity of building components?*
  - b. *What methods exist to assess the flexibility of building components?*
  - c. *Which assessment method is most relevant to assess the effect of flexibility measures on the circularity of a building component?*

A variety of circularity methods is available through literature. However, many of them are not relevant for building structures or applicable at a building component level. For other circularity assessment methods discussed in literature, the full method was not available. Based on its availability and applicability at a building component level, the Building Circularity Indicator method was found to be the most relevant assessment method for the study at hand.

No suitable method was found for the assessment of the flexibility of building components. Therefore a new flexibility assessment method was developed based on the characteristics of flexible design identified in sub-question 1a.

### **Case study**

5. *What is the current design of the floor system?*
  - a. *What are the dimensions of the current floor design?*
  - b. *What are the structural and technical properties of the current floor design?*
  - c. *What building services are integrated in the current floor design?*

The information on the dimensions and properties of the current design that could be shared within the confidentiality restrictions can be found in Chapter 8.1. The current design has a low height in comparison with the traditional floor systems and existing flexible floor designs. Its weight is within the range of the groove floors and the hollow core slab.

6. *How can the flexibility and circularity of the current design of the floor system be improved?*
  - a. *How circular is the current design of the floor system?*
  - b. *How flexible is the current design of the floor system?*
  - c. *Which aspects of the current floor design can be redesigned to improve the flexibility and circularity of the floor system effectively?*

Based on the circularity assessment, the current floor design is not yet very circular. The material circularity of the design is on the low side and is brought down further by the scores for the disassembly factors. The material circularity of the design can be improved by increasing the utility factor of the design and through the use of non-virgin material input. The current design scores well on the disassembly factors regarding the connection design, but there is room for improvement on the disassembly factors of functional separation, functional independence, and technical life cycle coordination.

The flexibility score of the current design is low. The accessibility, independence, and interface simplicity of the design can be improved by no longer casting the different parts of the floor into place. The accessibility can further be improved by applying a removable coverage at either the top or the bottom of the floor. Both a load-bearing overcapacity and surplus space for building services can be realised by increasing the floor height. For this design choice, the interplay between flexibility and the circularity and cost aspect of material efficiency is of importance and should be thoroughly considered.

7. *What are the requirements for the design of the floor system?*
  - a. *What building code requirements are relevant for the design of the floor system?*
  - b. *What are the stakeholder requirements for the design of the floor system?*

The Dutch Building Decree and the Eurocodes dictate requirements for the load-bearing capacity in the ultimate limit state, the serviceability limit state, and under the combination of actions for accidental design situations. They also dictate requirements for the acoustic properties and the fire safety design of floors. The requirements from the building codes were compiled into an overview for application in the design process.



The stakeholder requirements are of a less quantitative and categorical nature than the building code requirements. The financial aspect of the floor design is of interest to most of the stakeholders. Both the investors and the builders want to ensure a good profit margin. To optimise the profit, both the costs of the floor design itself and the effects of the floor design on the costs of the rest of the building structure should be managed. Simplicity and ease of construction are of importance to the contractors and manufacturers involved in a building project. An uncomplicated assembly process requires fewer hours and less specialised work and reduces the chances of mistakes and associated failure costs. For the end-user, the quality and comfort of living are the most important. They do not want to be concerned with the floor in day-to-day life and want maintenance or upgrades to be able to be done swiftly and without too much intrusion into their lives or the rest of the building structure.

8. *Does the floor system meet the requirements when flexibility measures are included?*
  - a. *Does the floor system meet the building code requirements when flexibility measures are included?*
  - b. *Does the floor system meet the stakeholder requirements when flexibility measures are included?*

Several design concepts for a flexible floor design were devised. These design concepts were developed, verified, adapted, and sometimes discarded based on the building code and stakeholder requirements from sub-question 7. The complete verification of the building code requirements on load-bearing capacity, sound insulation, and fire safety requires further development and more detailed verification than included in this study.

9. *To what extent does the inclusion of flexibility measures in the floor design improve the circularity of the floor system?*
  - a. *How flexible is the floor design when flexibility measures are included?*
  - b. *How circular is the floor design when flexibility measures are included?*
  - c. *Is the circularity of the floor improved by the inclusion of flexibility measures in the design?*

The developed design concepts have the highest flexibility score of all the floors included in the comparison. This high flexibility score is a result of comparatively high scores on all of the characteristics of the flexibility assessment. This is especially true for the flexibility characteristics of accessibility, interface simplicity, and overcapacity. The scores on independence and integration also show a large improvement compared to the current floor designs, but compared to the other flexible floor designs the scores for these characteristics are more average.

For the circularity assessment of the developed design concepts, two versions are taken into consideration. In one version, the granulate material used as ballast for the acoustic properties is included as a recycled material and in the other version, this material is included as a virgin material. The use of the recycled ballast material has a significant positive effect on the circularity of the floor design, resulting in the highest circularity score of all the floors included in the comparison. When the ballast material is included as a virgin material, the circularity score is much lower. The circularity score based on solely the material properties is even slightly lower than for the current floor design. However, when the disassembly factors are included for the final circularity assessment, the developed design concepts have the second-highest circularity scores of all the floors included in the comparison. This is primarily the result of the good scores on the disassembly factors of functional separation, functional independence, and technical life cycle coordination.

The circularity of the floor design is improved by the inclusion of flexibility measures in the design. The improvement in the scores of the disassembly factors is a direct result of the improvement of the flexibility characteristic of independence. The high final circularity scores of the design concepts where a virgin material is used as ballast show that even if all the design choices are based on flexibility and cost consideration and do not further include considerations based on circularity, the design has an improved circularity score. The increased circularity score as a result of the use of a recycled ballast material can also be attributed to the design choices based on flexible design. The choice for a loose ballast material, instead of supplementing weight by adding extra cast concrete, is made from the design perspective of flexibility of the building services in combination with minimization of the total floor height. Because the ballast material is not integrated with the structural function of the floor, it is possible to use a non-structural or less high-grade material. Which makes it possible to choose a recycled material made from demolition waste.

10. To what extent does the inclusion of flexibility measures in the floor design affect the circularity of the building as a whole?
- How does the inclusion of flexibility measures in the floor design affect the rest of the building?
  - How is the circularity of the rest of the building affected by the inclusion of flexibility measures in the floor design?

The differences between the current floor design and the proposed design concepts that could influence the rest of the structure are a slight increase in the floor height and a reduction of the weight. As a result of the slight increase in floor height, the rest of the building design has to be adapted to accommodate the new design. Because the increase in height is minimal, it is not expected that this will result in a lot of additional material use. By virtue of the reduction in weight, the supporting structure has to bear a smaller load and, as a result, possibly a more material-efficient version of the supporting structure could be implemented.

Compared to most of the other floor systems discussed, the developed design concepts score well on circularity and would thus positively influence the circularity of the building. As the additional material use in the building as a result of the height increase of the floor designs is expected to be minimal and a decrease of material use is conceivably possible due to the reduction in weight. The application of the developed design concepts would likely positively influence the overall circularity of the building.

## 12.2 Main research question

*To what extent can flexibility measures improve the circularity of prefabricated floor systems in residential buildings?*

To answer the main research question, multiple floor designs were assessed on both their flexibility and circularity. In addition, a case study was done on the development of floor designs based on flexible design choices. The circularity and flexibility of both the existing floor designs and the developed design concepts are plotted against each other in Figure 73. This figure shows a significant positive correlation between the flexibility and circularity scores of the floor systems. The direct relation between the flexibility and circularity scores lie in the positive impact of the flexibility characteristics of independence and integration on a number of the disassembly factors of the circularity assessment. In addition, flexible design offers the possibility that a floor element or even the entire building remains in use longer without the need for major interventions or additional material use. However, this is not represented in the calculation of the circularity score.

In conclusion, the implementation of flexibility measures can improve the circularity of prefabricated floor systems in residential buildings through the positive effect of certain characteristics of flexible design on the disassembly factors of functional separation, functional independence, and technical life cycle coordination used to determine the circularity of a design.

## 13 Recommendations

Further research can be done in two directions. To be able to put the proposed floor designs into practice, further research and development are required. In addition, the flexibility assessment method developed for this thesis can benefit from further research and development. The different aspects that should be addressed in the further research of these two directions are listed below.

### 13.1 Recommendations for the further development of the flexibility assessment method

- *Feedback from an expert panel*  
The current version of the flexibility assessment method could be presented to and discussed with a panel of experts to gather feedback on the completeness of the method, its applicability in practice, and other possible points of improvement. This feedback could be used as input for the development of an improved version of the flexibility assessment method.

- *Refining of the scoring system*  
Currently, every flexibility characteristic is scored on a scale from 0 to 4. It is possible that the quality of the output of the flexibility assessment method can be improved by refining this distribution. A distinction could be made between the different amounts of increase between certain score levels and a different number of scoring levels could be used for different flexibility characteristics. The possibilities for the optimisation of the scoring system and its effect on the output of the flexibility assessment method should be investigated.
- *Expansion of the overcapacity flexibility characteristic*  
Currently, the scoring of the flexibility characteristic of overcapacity is focused on the surplus space available for building services and the load-bearing overcapacity. In the further development of the flexibility assessment method, the properties of the floor elements regarding fire safety and acoustics should also be included in the overcapacity score, as these properties also affect the usability of the floor element in different use-cases.
- *Applicability for different building functions*  
The current version of the flexibility assessment method has been developed based on a building with a residential function. It could be interesting to develop additional versions of the flexibility assessment method with other functions in mind or to further develop the existing version of the flexibility assessment method for it to be more generally applicable to different building functions. The latter could, for example, include labels for different flexibility scores indicating for what different functions the floor element would be suitable.
- *Applicability to different building components*  
The current version of the flexibility assessment method has been specifically designed for application to floor systems and the particular combination of load-bearing capacity and building services associated with these building components. It could be interesting to further develop the flexibility assessment method to also be applicable to other building components or to develop additional versions of the flexibility assessment method for application to other building components. In order to do so, it should be investigated what properties of the different building components affect the flexibility characteristics of the flexibility assessment method and if these properties are compatible to be combined in a single assessment method.

### 13.2 Recommendations for the further development of the floor designs

- *Further calculation of prestressing*  
Currently, only preliminary calculations are done on the prestressing of the floor designs. In addition, the effect of prestressing in the longitudinal direction on the load-bearing capacity of the floor designs in the transversal direction is not taken into consideration. Further development of the floor designs requires more advanced calculations and detailing of the prestressing of the floor designs.
- *Horizontal stability calculations*  
The horizontal stability and the effect of the accidental load combination on the horizontal stability are not included in the current design process. This should be included in the further development of the floor designs.
- *Detailing*  
The design and calculation of the details of the floor systems are not yet included in the current design process. The placement and detailing of the reinforcement in the floor should be worked out in the further development of the floor designs. In addition, the connections of the design should be designed and verified through calculations. For the circularity score of the floor design, the demountability and accessibility of the connections are of importance.
- *Detailed design of rib openings*  
Currently, only the distance from the end of the span in which the rib opening could be placed is determined using a reduced cross-section height. The stresses in the concrete and

reinforcement steel around the rib opening should be calculated and verified. In addition, the shape and location of the rib openings could be optimised. In the design process, the secondary bending moments as a result of the shear forces in the frame of the rib opening are not considered, this could influence the optimal location of the rib openings.

- *Further investigation of sound insulation*

The elaboration on the sound insulation design is currently limited. In the further development of the floor designs, more advanced calculations need to be done on the sound insulation. In addition, the possibility of the use of a cavity structure for sound insulation should be investigated.

- *Advanced fire safety design*

Currently, in the verification of the fire safety of the floor designs, only the fire resistance with regard to the load-bearing capacity is included through simplified calculations. In the further development of the floor designs, advanced calculations or physical tests are required to verify the load-bearing fire resistance. In addition, the fire resistance regarding the separating function of the floor systems has to be verified.

- *Design of cover panels*

The design of the cover panels is currently not worked out and is limited to the discussion of design considerations regarding material choice and connections. For the further development of the floor designs, these design choices should be further investigated and worked out. Also, the effect of the design choices for the cover panels on the fire safety and acoustic performance of the floor designs should be assessed.

- *Design of the beam for option B*

The design of the beam for design option B is only done rudimentarily. Because the properties of the design for option A.ii are preferable to the design for option B.ii, further calculations on the beam have no priority. If the design for option B.ii is further developed, further calculations also need to be done on the beam. This includes the effect of the steel beam on the acoustics and fire safety properties of the floor system

- *Structural design for transportation and construction*

The structural integrity of the floor designs during construction and transportation is currently not included in the structural design and should be worked out during further development of the floor designs. As the need for propping can delay the construction process and increase the costs of a building project, this should be taken into consideration in the calculations and design of the floor system during the construction phase.

- *Further research into building services*

The research done into the building services incorporated in the floor is limited. Further research should be done into the requirements for floor design as a result of the building services incorporated within the floor, as well as into the expected future developments in the field of building services that could affect floor design.

- *Industrialised production process requirements*

Due to a lack of information available on the industrialised production process intended for the Fijn Wonen housing concept, the requirements as a result of this production process are only included in the design process to a minimal extent. For the practical feasibility of the floor designs, the effect of the production process on the design requirements should be investigated further and included in the design where necessary.

- *Cost analysis*

Because costs play an important role in the building industry, a more in-depth analysis of the cost influencing factors should be done, including a larger variety of design aspects, to get a better picture of what design choices influence the costs of a floor system and a building project. In addition, a full cost calculation of the proposed design concepts should be done. The results of these cost calculations should be compared to more complete costs calculations of other existing floor designs to get a more accurate perspective on how the costs of the design concepts compare to the existing floor designs.

- *Optimisation of the rib distribution*

In the current designs of the floor system, the ribs are equally distributed over the width of the floor system. It is possible that a different distribution of the ribs would result in a more optimal design. It could be interesting to investigate the possibilities of different rib distributions and their effect on the floor properties. In this exploration, the design option of a floor that is load-bearing in two directions could be reconsidered if an optimal distribution of the ribs can be found that minimises the amount of opening that needs to be made for the routing of the building services.

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# Appendices

## Appendix A Literature study flexible design

### A.1 Approach

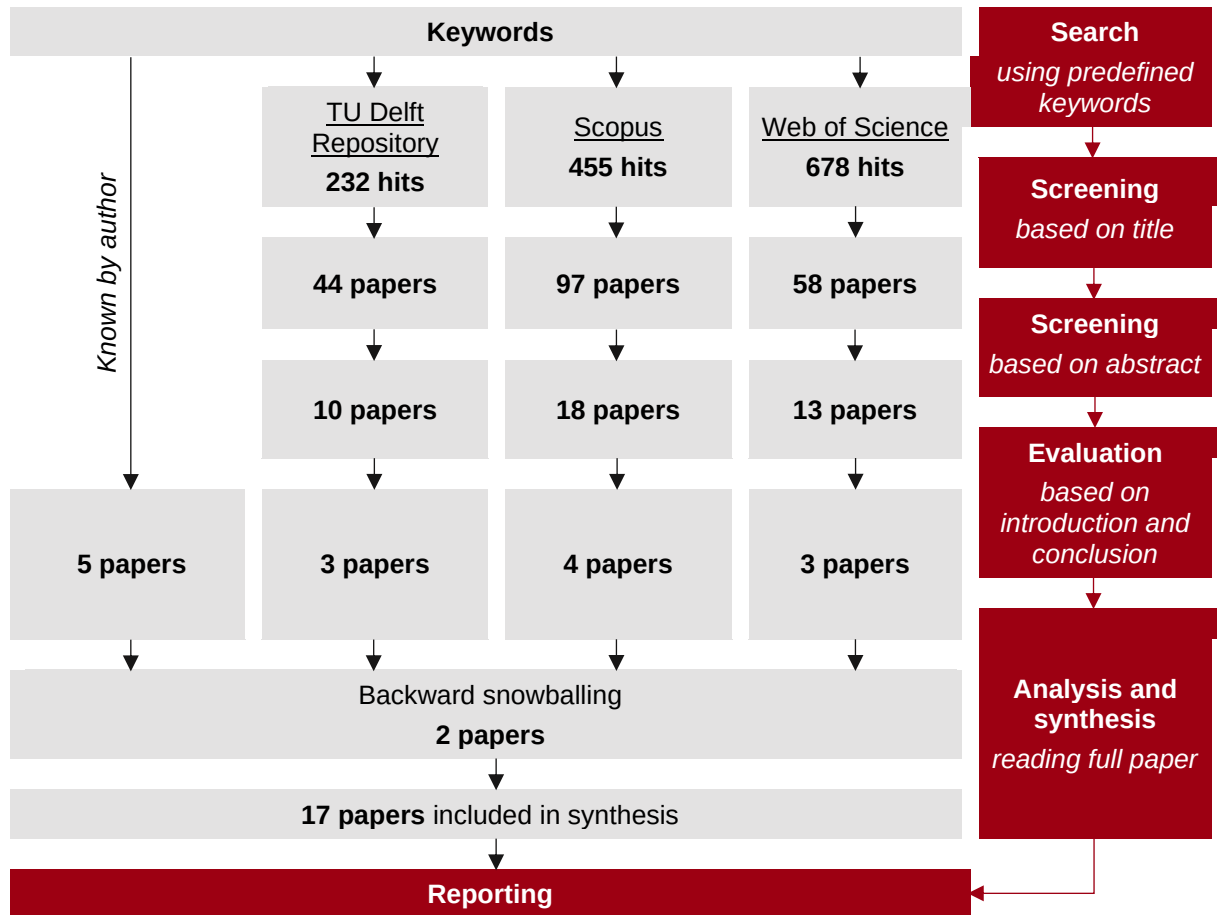


Figure A.1: Approach for literature study research question 1a

To provide a thorough review of the existing literature on flexible design, the steps outlined in Figure A.1 were taken. The keywords used to formulate the search term can be found in Table A.1. To formulate the search term, the wildcard symbol (\*) was used to search for different word endings, like for flexibility and flexible, and the Boolean operators AND and OR were used to combine keywords and include synonyms respectively (Beatty, 2016; TU Delft Library, n.d.-a). The search engines used are the TU Delft Repository, Scopus, and Web of Science, based on availability and recommendation through the TU Delft Library (TU Delft Library, n.d.-b). To keep the total number of hits manageable, filters were applied. The filters applied are given below per search engine. Also, a couple of sources are included that were already known by the author to be relevant to the research question at hand. Additionally, articles were found through backward snowballing using the reference lists of the sources found.

Table A.1: Keywords for search term research question 1a

|                                                                                                         |     |                                                                                                              |     |                                              |     |                                                                               |
|---------------------------------------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------|-----|----------------------------------------------|-----|-------------------------------------------------------------------------------|
| Flexib*<br><i>Flexibility</i><br><i>Flexible</i><br>Adaptab*<br><i>Adaptability</i><br><i>Adaptable</i> | AND | Indicators<br>Characteristics<br>Categories<br>Classification<br>Factors<br>Measures<br>Features<br>Concepts | AND | Design*<br><i>Design</i><br><i>Designing</i> | AND | Circular economy<br>Sustainab*<br><i>Sustainability</i><br><i>Sustainable</i> |
|---------------------------------------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------|-----|----------------------------------------------|-----|-------------------------------------------------------------------------------|

## A.2 Search

### A.2.1 Scopus

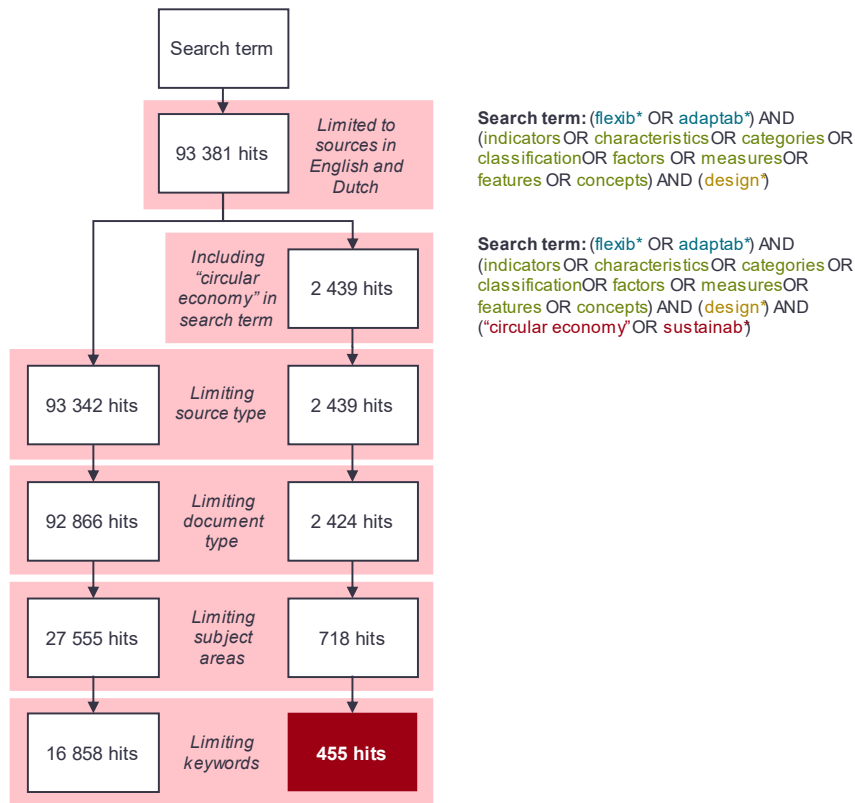


Figure A.2: Flow chart of filters applied to search term Scopus research question 1a

The search term was applied to the fields article title, abstract, and keywords, which is the standard setting of Scopus. Right away, an initial filter was applied to limit the search to sources in Dutch and English. This results in the first amount of hits, shown at the top of Figure A.2. Initially, only the first three categories of keywords were included in the search term. This resulted in too many hits to realistically process. Because the scope of this research is flexibility as a means to achieve circularity, "circular economy" and the related keywords sustainability and sustainable were added to make the number of hits more manageable.

#### Limiting source type

The source types were limited to the main source types as identified by Scopus (Elsevier, 2020):

- Journals
- Trade journals
- Books
- Book series
- Conference material
- Reports

#### Limiting document type

The inclusion of document types was based on their perceived relevance to the research at hand and the expected amount of primary information to be found in the document. An overview of both the included and excluded document types is given below.

### Included

- Article
- Book and book chapter
- Conference paper
- Review
- Report
- Business article

### Excluded

- Abstract report
- Data paper
- Editorial
- Erratum
- Letter
- Note
- Retracted article
- Short survey
- Undefined

### **Limiting subject areas**

Certain subject areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain subject areas is outlined below.

- **Difference in scale**  
This research regards flexibility at a (building)component level. Some subject areas were excluded because they operate at a significantly different scale.  
*Excluded subject areas: Material science, Physics and astronomy, Energy, Biochemistry, genetics and molecular biology, Chemistry, Earth and planetary sciences, Chemical engineering, Neuroscience, and Immunology and microbiology.*
- **Unrelated to product design**  
The literature study is aimed at finding indicators and design factors that influence the flexibility of a product or component. Some subject areas are not related to the design of objects.  
*Excluded subject areas: Computer science, Mathematics, Social sciences, Business, management and accounting, Decision sciences, Psychology, Pharmacology, toxicology and pharmaceuticals, and Economics, econometrics and finance.*

### **Limiting keywords**

Finally, a number of keywords were excluded from the search. The reasoning for excluding certain keywords is outlined below.

- **Keywords that indicate a different interpretation of the search term than intended**  
Certain keywords in the search term can be interpreted in different ways. For example, flexibility can be interpreted as the ability to be easily modified or to describe the bendiness of a material or object. Keywords that indicate a different interpretation of the search than intended were excluded from the search.  
*Excluded keywords: Stiffness and Elasticity.*
- **Keywords that indicate dissociation with product design**  
Certain keywords point to a different field of research and knowledge, unconnected with the design of an object.  
*Excluded keywords: Human, Humans, Female, Male, Adult, Middle aged, Aged, Major clinical study, Computer simulation, Procedure, Treatment outcome, Adolescent, Mathematical models, Clinical trial, Algorithms, Physiology, Young adult, Child, Computer software, Aged 80 and over, Nonhuman, Psychology, Automation, Prospective studies, Physiology, Controlled clinical trial, Organization and management, Prospective study, Exercise, Retrospective studies, Education, Animals, Retrospective study, Quality of life, Range of motion, articular, Systems analysis, Multicentre study, Computer architecture, Control systems, Human experiment, Cross-sectional studies, Simulation, Cohort analysis, Cross-sectional study, Animal, Follow-up studies, Economics, Normal human, Muscle strength, Real time systems, Energy efficiency, Very elderly, Signal processing, Students, Internet, Physical activity, Psychological aspect, Wireless telecommunication systems, Range of motion, Rehabilitation, Age, Drug efficacy, Embedded systems, Patient care, Patient satisfaction, Body mass, Health care delivery, Vibrations (mechanical), Robustness (control systems), Disease severity, Surgical technique, Engineering education, Computer program, Project management, Age factor, Bandwidth, Monitoring, Software, Curricula, Health care policy, Health promotion, Mental health, Organization, Primary health care, Health care planning, Health services research, Leadership, Management, Public health, Community care, Health care personnel,*

Teaching, Water resources, Economic and social effects, Health care quality, and Health education.

## A.2.2 TU Delft Repository

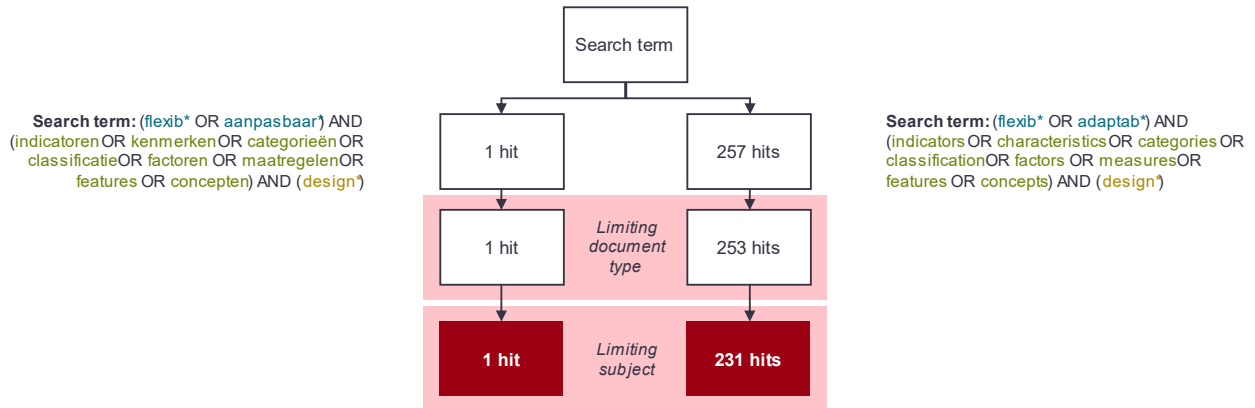


Figure A.3: Flow chart of filters applied to search term TU Delft Repository research question 1a

As shown in Figure A.3, the search terms were put into the TU Delft Repository both in Dutch and in English. Because the amount of hits is not too excessive, the fourth category of keywords related to circular economy was not included. To limit the number of irrelevant hits, filters were applied to the document type and subject of the results.

### Limiting document type

The selection applied to the search results of the TU Delft Repository is similar to that of the search results of Scopus, with the addition of doctoral theses.

#### Included

- Doctoral thesis
- Conference paper
- Journal article
- Report
- Book chapter
- Review
- Contribution to periodical

#### Excluded

- Abstract
- Other (PowerPoint presentations)

### Limiting subject

A number of subject keywords were excluded from the search. The reasoning for excluding certain keywords is outlined below.

- Keywords that indicate a different interpretation of the search term than intended  
*Excluded subjects: Flexible mould*
- Keywords that indicate a difference in scale  
*Excluded subjects: Particle image*
- Keywords that indicate dissociation with product design  
*Excluded subjects: Simulation and Situation awareness*



### A.2.3 Web of Science

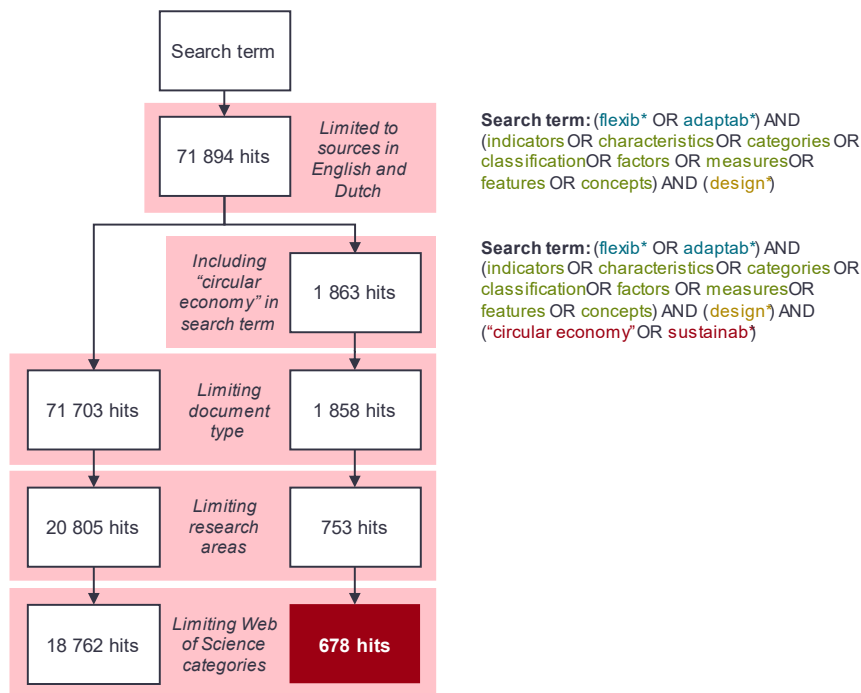


Figure A.4: Flow chart of filters applied to search term Web of Science research question 1a

The search term for Web of Science was set to search in Topic, which includes the title, abstract, author keywords, and Keywords Plus. The initial results were directly filtered to only include sources in Dutch and English. Initially, only the first three categories of keywords were included in the search term. Similar to the approach for Scopus, the keywords "circular economy", sustainability and sustainable were added to make the number of hits more manageable.

#### Limiting document type

The document types selected are comparable to those selected for Scopus.

##### Included

- Article
- Proceedings paper
- Review
- Book chapter
- Early access article
- Reprinted article
- Book

##### Excluded

- Editorial material
- Note
- Letter
- Retracted publication
- Data paper
- Correction
- Book review
- Meeting abstract
- Software review

#### Limiting research areas

Certain research areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain research areas is outlined below.

- Difference in scale  
This research regards flexibility at a (building)component level. Some subject areas were excluded because they operate at a significantly different scale.  
*Excluded research areas: Material science, Energy fuels, Biochemistry molecular biology, Chemistry, Geochemistry geophysics, Electrochemistry, Neurosciences neurology, Biotechnology applied microbiology, Microbiology, Optics, Polymer science, Metallurgy metallurgical engineering, Cell biology, Spectroscopy, Geography, and Crystallography*

- Unrelated to product design

The literature study is aimed at finding indicators and design factors that influence the flexibility of a product or component. Some subject areas are not related to the design of objects.

*Excluded research areas: Physics, Astronomy astrophysics, Immunology, Computer science, Mathematics, Social sciences other topics, Mathematical methods in social sciences, Social work, Business economics, Operations research management science, Psychology, Psychiatry, Pharmacology Pharmacy, Toxicology, Automation control systems, Education educational research, Public environmental occupational health, Mathematical computational biology, Remote sensing, Thermodynamics, General internal medicine, Radiology nuclear medicine medical imaging, Biophysics, Information science library science, Medical informatics, Research experimental medicine, Oceanography, Life sciences biomedicine other topics, Otorhinolaryngology, Public administration, Genetics heredity, Cardiovascular system cardiology, Meteorology atmospheric sciences, Geriatrics gerontology, Obstetrics gynecology, Government law, Oncology, Plant sciences, Endocrinology metabolism, Nutrition dietetics, Physiology, Behavioural sciences, Gastroenterology hepatology, Zoology, Urology nephrology, Mining mineral processing, Marine freshwater biology, Infectious diseases, Linguistics, Audiology speech language pathology, Biodiversity conservation, Anaesthesiology, Integrative complementary medicine, Ophthalmology, Health care sciences services, Rehabilitation, Social issues, International relations, Biomedical social sciences, Medical ethics, Mineralogy, Criminal penology, Emergency medicine, Entomology, and Evolutionary biology.*

### Limiting Web of Science categories

All sources covered by the Web of Science core collection are also assigned a subject category. These categories are similar to the research areas but can still provide the next level of filtering.

- Difference in scale

*Excluded Web of Science categories: Engineering biomedical, Engineering chemical, Geography physical, Haematology, Microscopy, and Nanoscience nanotechnology.*

- Unrelated to product design

*Excluded Web of Science categories: Health policy services, Agronomy, Forestry, Soil science, Rheumatology, Agriculture dairy animal science, Agricultural economic policy, Dermatology, Sociology, Humanities multidisciplinary, Virology, Substance abuse, International relations, Transplantation, Development studies, Criminology penology, Communication, Emergency medicine, Evolutionary biology, Anthropology, Geology, History philosophy of science, Archaeology, Entomology, Social issues, Anatomy morphology, History, Parasitology, Pathology, Palaeontology, Family studies, Demography, Developmental biology, Medicine legal, Reproductive biology, Mineralogy, Social science biomedical, Tropical medicine, Asian studies, Dance, Ethnic studies, Philosophy, Integrative complementary medicine, Oncology, Social work, and Radiology nuclear medicine medical imaging.*

## A.3 Screening

*The screening of all the sources found was done in two phases. First, all of the hits were screened based on their title. Then, a second screening took place based on the abstracts of the remaining sources. In some cases, sources were also excluded because the full article was not available through either open access or TU Delft resources. Duplicate hits were also filtered. In Figure A.1: Approach for literature study research question 1a*

, the duplicate hits are counted under the search engine they were first found with, with the search order being left to right.

### Screening based on title

Based on the title, certain hits were excluded according to the following criteria.

- Difference in scale

This research regards flexibility at a (building)component level. Certain hits are excluded because their titles indicate that their scope is at a significantly different scale.

- Different interpretation of search term than intended

Hits are excluded when their title indicates a different interpretation of certain search term keywords than intended.

- Unrelated to product design  
Hits are excluded when their title indicates that their scope is not related to product design.

### Screening based on abstract

Hits are included if the abstract contains mention of or reference to factors or measures that influence the flexibility of design.

## A.4 Evaluation

Further evaluation of the search hits for the inclusion in the literature study was done based on the introduction and conclusion. The criteria for inclusion is similar to that of the screening based on the abstract, the introduction or the conclusion should contain mention of or reference to factors or measures that influence the flexibility of design. During the evaluation, the scope or scale of the design was also taken into consideration. The design or design factors should be relevant at a component or product level. This means that, for example, papers on the effect of spatial layout on the flexibility of a building were excluded.

In some cases, no conclusive judgement could be made based on the introduction and conclusion of the paper only. In this case, the rest of the paper was scanned based on its structure, headings, figures.

## A.5 Analysis and synthesis

*The papers remaining after the screening and evaluation of the search hits were fully read. During the reading of the sources, notes were kept on the design factors mentioned throughout the texts. Notes were also taken of references to other papers and authors. When a certain source was referenced by more than 1 paper, it was also screened and evaluated based on the same process as the initial search hits. If the source was deemed relevant, it was included in the literature study. This process is referred to as 'backward snowballing' in Figure A.1:  
Approach for literature study research question 1a*

. Table A.2 gives an overview of all sources included in the literature review.

Table A.2: Sources included in literature study research question 1a

| Search Engine | Authors                                   | Title                                                                                                                                                                       | Year | Document type                    | DOI                               |
|---------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------|-----------------------------------|
| Scopus        | T. Brunoe, A. Andersen, K. Nielsen        | Changeable manufacturing systems supporting circular supply chains                                                                                                          | 2019 | <a href="#">Conference paper</a> | 10.1016/j.procir.2019.05.007      |
| Scopus        | M. Di Sivo, C. Celucci                    | Flexibility and cooperation: The characteristics of low cost home                                                                                                           | 2013 | <a href="#">Conference paper</a> | 10.3850/978-981-07-5354-2-H-2-128 |
| WoS           | J. Esper                                  | Modular, adaptive, reconfigurable systems: Technology for sustainable, reliable, effective, and affordable space exploration                                                | 2005 | <a href="#">Conference paper</a> | 10.1063/1.1867227                 |
| TU Delft/ WoS | B. Geldermans, M. Tenpierik, P. Luscure   | Circular and Flexible Infill Concepts: Integration of the Residential User Perspective                                                                                      | 2019 | <a href="#">Journal article</a>  | 10.3390/su11010261                |
| TU Delft      | R. Geraedts                               | FLEX 4.0: A Practical Instrument to Assess the Adaptive Capacity of Buildings                                                                                               | 2016 | <a href="#">Journal article</a>  | 10.1016/j.egypro.2016.09.102      |
| Known         | R. Gijsbers                               | Aanpasbaarheid van de draagstructuur: Veranderbaarheid van de drager op basis van gebruikerseisen in het kader van Slimbouwen                                               | 2011 | <a href="#">Doctoral thesis</a>  |                                   |
| Scopus/ WoS   | O. Heidrich, J. Kamara, S. Maltese et al. | A critical review of the developments in building adaptability                                                                                                              | 2017 | <a href="#">Journal article</a>  | 10.1108/IJBPA-03-2017-0018        |
| Known         | M. Hermans, R. Geraedts, E. Rijn et al.   | Gebouwen met toekomstwaarde! Het bepalen van de toekomstwaarde van gebouwen vanuit het perspectief van adaptief vermogen, financieel rendement en duurzaamheid: Eindrapport | 2014 | <a href="#">Report</a>           | 10.13140/2.1.1947.4561            |
| Snow-balling  | M. Keymer                                 | Design strategies for new and renovation construction that increase the capacity of buildings to accommodate change.                                                        | 2000 | <a href="#">Master thesis</a>    |                                   |

| Search Engine | Authors                                   | Title                                                                                         | Year | Document type                    | DOI                             |
|---------------|-------------------------------------------|-----------------------------------------------------------------------------------------------|------|----------------------------------|---------------------------------|
| Known         | M. Landman                                | Technical Building Properties with the Probability of Elongating the Functional Service Life  | 2016 | <a href="#">Master thesis</a>    |                                 |
| WoS           | A. Manewa, M. Siriwardena, A. Ross et al. | Adaptable buildings for sustainable built environment                                         | 2016 | <a href="#">Journal article</a>  | 10.1108/BEPAM-10-2014-0053      |
| Known         | B. Ross, D. Chen, S. Conejos et al.       | Enabling Adaptable Buildings: Results of a Preliminary Expert Survey                          | 2016 | <a href="#">Journal article</a>  | 10.1016/j.proeng.2016.04.009    |
| Scopus/WoS    | N. Sadafi, M. Zain, M. Jamil              | Design criteria for increasing building flexibility: Dynamics and prospects                   | 2014 | <a href="#">Journal article</a>  | 10.30638/eemj.2014.045          |
| Known         | R. Schmidt, K. Vibeak, S. Austin          | Evaluating the adaptability of an industrialized building using dependency structure matrices | 2014 | <a href="#">Journal article</a>  | 10.1080/01446193.2013.847274    |
| Snow-balling  | R. Webb, J. Kelly, D. Thomson             | Building services component reuse: an FM response to the need for adaptability                | 1997 | <a href="#">Journal article</a>  | 10.1108/02632779710188306       |
| WoS           | M. Zawidzki                               | Deployable Pipe-Z                                                                             | 2016 | <a href="#">Journal article</a>  | 10.1016/j.actaastro.2016.05.023 |
| TU Delft      | J. Zwakhals, P. Taneja, H. Ligteringen    | Quay wall design for an uncertain future                                                      | 2012 | <a href="#">Conference paper</a> |                                 |

## A.6 Results

All the factors mentioned in the literature to be of importance for flexible design can be found in Table A.3.

Table A.3: Flexible design factor found in the literature study for research question 1a

| Name                  | Also known as                                                                                                                             | Sources                                                                                                                                                                                                                                     | Meaning                                                                                                          |
|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| <b>Accessibility</b>  | Accessible, <i>bereikbaarheid</i> , physical access, reachability, <i>toegankelijkheid</i>                                                | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Ross et al., 2016)                                                                                                                | Access to the component that needs to be adapted without hindrance from other components.                        |
| <b>Adjustability</b>  | <i>Regelbaarheid</i>                                                                                                                      | (Gijsbers, 2011)                                                                                                                                                                                                                            | The possibility to change the functional performance of a component without changing it technically.             |
| <b>Breacheability</b> | <i>Doorbreekbaarheid</i>                                                                                                                  | (Gijsbers, 2011)                                                                                                                                                                                                                            | The possibility to perforate a component while the main form stays intact.                                       |
| <b>Demountability</b> | Demountable, design for deconstruction, design for disassembly, dismantlable, disassembly, separable, simplify demolition                 | (Geldermans et al., 2019a; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Schmidt et al., 2014; Webb et al., 1997; Zwakhals et al., 2012) | The capacity to deconstruct the components from the building and deconstruct components into their constituents. |
| <b>Durability</b>     | Durable                                                                                                                                   | (Di Sivo & Cellucci, 2013; Sadafi et al., 2014; Zwakhals et al., 2012)                                                                                                                                                                      | The capacity of materials and systems to continue to be useful after an extended period of time and usage.       |
| <b>Fire safety</b>    | <i>Brandveiligheid</i> , fire protection, fire resistance, fire safety design                                                             | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Keymer, 2000; Landman, 2016; Manewa et al., 2016)                                                                                                             | The degree to which a building(component) can resist the spread of fire and deterioration due to fire.           |
| <b>Independence</b>   | Clustering, <i>desintegratie</i> , flexibility, layering of components, no integration, reduced interaction, segregation, separation      | (Di Sivo & Cellucci, 2013; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Landman, 2016; Manewa et al., 2016; Sadafi et al., 2014; Schmidt et al., 2014)                                                              | The technical separation of elements of different service lives and functions.                                   |
| <b>Insulation</b>     | Acoustics, acoustics and thermal insulation, <i>geluidswerendheid</i> , insulation and acoustics, noise, <i>thermische isolatiewaarde</i> | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Landman, 2016; Manewa et al., 2016)                                                                                                                                                 | The degree of thermal and acoustic insulation between different building parts.                                  |

| Name                        | Also known as                                                                                                                                  | Sources                                                                                                                                                                                                      | Meaning                                                                                                                    |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| <b>Integration</b>          | Clustering, <i>integration</i>                                                                                                                 | (Gijsbers, 2011; Schmidt et al., 2014)                                                                                                                                                                       | The technical coupling of components that will never be adapted separately.                                                |
| <b>Interface simplicity</b> | Flexible interfaces, mechanical connections, pluggable connections, simplicity                                                                 | (Esper, 2005; Heidrich et al., 2017; Ross et al., 2016; Sadafi et al., 2014)                                                                                                                                 | The use of uncomplicated mechanical connections between elements.                                                          |
| <b>Mergeability</b>         | <i>Samenvoegbaarheid</i>                                                                                                                       | (Gijsbers, 2011)                                                                                                                                                                                             | The possibility to merge two parts into one component.                                                                     |
| <b>Modularity</b>           | Modularization, modular, <i>modulatie, universele moduulmaten</i>                                                                              | (Di Sivo & Cellucci, 2013; Esper, 2005; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Webb et al., 1997; Zawidzki, 2016) | The consistent use of matching building blocks that can form into a larger component or system.                            |
| <b>Movability</b>           | Mobility, movable, <i>verplaatsbaar, verplaatsbaarheid</i>                                                                                     | (Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                                                                              | The possibility to place a building component at a new location.                                                           |
| <b>Overcapacity</b>         | Capacity, <i>overcapaciteit, overgedimensioneerd</i> , redundancy, reserve capacity, surplus                                                   | (Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014)                                                                           | The capacity to accommodate higher technical specifications than initially required.                                       |
| <b>Reconfigurability</b>    | Adjustability, <i>indelingsflexibiliteit</i> , rearrangeable, <i>reconfigureerbaar</i> , transformable, <i>veranderbaarheid</i> , versatile    | (Esper, 2005; Geraedts, 2016; Gijsbers, 2011; Hermans et al., 2014; Manewa et al., 2016; Schmidt et al., 2014; Zawidzki, 2016)                                                                               | The possibility to rearrange parts or components in relation to each other.                                                |
| <b>Remountability</b>       | <i>Hoogwaardig hergebruik</i> , reassembly, reusable, reuse                                                                                    | (Geldermans et al., 2019a; Gijsbers, 2011; Manewa et al., 2016; Sadafi et al., 2014)                                                                                                                         | The possibility to directly reuse a component without or with only minor repairs.                                          |
| <b>Removability</b>         | <i>Afstotingsflexibiliteit</i> , disposability, ejectable, rejectability, <i>verwijderbaarheid</i>                                             | (Geraedts, 2016; Gijsbers, 2011; Hermans et al., 2014; Manewa et al., 2016)                                                                                                                                  | The capacity to remove a component from a system without negative consequences to the technical functioning of the system. |
| <b>Replaceability</b>       | Exchangeable, refitable, replaceable, <i>vervangbaar</i>                                                                                       | (Geraedts, 2016; Gijsbers, 2011; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                                                                                                           | The possibility to replace a component with the same component.                                                            |
| <b>Scalability</b>          | Elastic, elasticity, expendable, extendable, <i>inkrimpbaar</i> , scalable, <i>uitbreidbaar, uitbreidingflexibiliteit, volumeflexibiliteit</i> | (Brunoe et al., 2019; Geraedts, 2016; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Landman, 2016; Manewa et al., 2016; Schmidt et al., 2014; Zwakhals et al., 2012)                          | The capacity of the building or building component to change in size or capacity.                                          |
| <b>Splitability</b>         | <i>Deelbaarheid</i>                                                                                                                            | (Gijsbers, 2011)                                                                                                                                                                                             | The possibility to split one component into two or more parts.                                                             |
| <b>Standardisation</b>      | Compatibility, interchangeable, regularity, universal                                                                                          | (Di Sivo & Cellucci, 2013; Esper, 2005; Gijsbers, 2011; Heidrich et al., 2017; Keymer, 2000; Manewa et al., 2016; Ross et al., 2016; Sadafi et al., 2014; Webb et al., 1997; Zwakhals et al., 2012)          | The use of the same component sizes and construction details throughout the building.                                      |
| <b>Transformability</b>     | <i>Vervormbaarheid</i>                                                                                                                         | (Gijsbers, 2011)                                                                                                                                                                                             | The possibility to transform a component so that the main form changes.                                                    |
| <b>Upgradability</b>        | <i>Kwaliteit, opwaardeerbaarheid, opwaarderingsflexibiliteit</i> , refitable                                                                   | (Di Sivo & Cellucci, 2013; Esper, 2005; Gijsbers, 2011; Heidrich et al., 2017; Hermans et al., 2014; Schmidt et al., 2014)                                                                                   | The possibility to improve the performance of a component.                                                                 |

## Appendix B Interviews

### B.1 Interview guides

#### Goals of the interview:

- To explore the possibilities and challenges of implementing flexibility measures in floor design.
- Flexibility is the capacity of an object to adapt to changing circumstances and requirements without the need for intrusive intervention.
- Flexibility is intended as a means to contribute to circularity.

#### Interview method:

- Semi-structured interview, guiding questions with the possibility to delve into topics.

#### Audio recording:

- With the consent of the interviewee, the audio of the interview is recorded so that the interviewer can focus on the interview.

#### Use of data and confidentiality:

- Reference to informed consent sheet.
- The data collected will be anonymised for the use in the Master thesis report.
- The notes and audio recordings will be kept on a secured server with two-step verification

Table B.1: Interview guide for designers

| Designers         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                  |
|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Activity          | Comments/Question                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Approximate Time |
| Introduction      | <ul style="list-style-type: none"><li>- Costumery pleasantries</li><li>- Introduction of self</li><li>- Review of interview process<ul style="list-style-type: none"><li>o Goals of the interview</li><li>o Interview method</li><li>o Audio recording</li><li>o Use of data and confidentiality</li></ul></li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 5 min.           |
| Structured topics | <p><u>Topic 1: Flexibility of design</u></p> <ul style="list-style-type: none"><li>- <b>Q1a</b> Can you tell me about the current state of flexibility in <b>[the design of building services/structural design/product development/architecture]</b>?<br/>Kunt u me vertellen over de huidige staat van flexibiliteit in <b>[het ontwerpen van installaties/het constructief ontwerpen/product ontwikkeling/de architectuur]</b>?<ul style="list-style-type: none"><li>o Can you give me an example of ...?</li><li>o What is your experience with ...?</li><li>o How are flexibility measures included in ...?</li></ul></li><li>- <b>Q1b</b> How do you currently include flexibility in your design process?<br/>Op welke manier neemt u flexibiliteit mee in het ontwerpproces?<ul style="list-style-type: none"><li>o Can you give me an example of ...?</li></ul></li></ul> | 35 min.          |



|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |  |
|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
|  | <ul style="list-style-type: none"> <li>○ What is your experience with ...?</li> <li>○ How are flexibility measures included in ...?</li> </ul> <ul style="list-style-type: none"> <li>- <b>Q1c</b> What are the ongoing developments regarding flexibility in <b>[building services/structural design/product development/architecture]</b>?<br/> Wat zijn de huidige ontwikkelingen op het gebied van flexibiliteit in <b>[installatietechniek/constructief ontwerpen/product ontwikkeling/architectuur]</b>? <ul style="list-style-type: none"> <li>○ Can you give me an example of ...?</li> <li>○ What is your experience with ...?</li> <li>○ How are flexibility measures included in ...?</li> <li>○ How do you expect ... to evolve?</li> </ul> </li> <li>- <b>Q1d</b> In my research I define flexibility as “the capacity of an object to adapt to changing circumstances and requirements without the need for intrusive intervention”. What would be an “intrusive intervention” to you?<br/> In mijn onderzoek definieer ik flexibiliteit als “het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen zonder de noodzaak voor een ingrijpende ingreep”. Wat zou voor u een “ingrijpende ingreep” zijn? <ul style="list-style-type: none"> <li>○ Would ... be too intrusive?</li> <li>○ What hindrance would you expect in case of ...?</li> <li>○ How often (time period) would you be ok with ...?</li> </ul> </li> </ul> <p><u>Topic 2: Flexibility of floors</u></p> <ul style="list-style-type: none"> <li>- <b>Q2a</b> What is a floor to you?<br/> Wat is een vloer voor u? <ul style="list-style-type: none"> <li>○ What characteristics define a floor?</li> <li>○ What should a floor be able to do?</li> <li>○ How important is ...?</li> </ul> </li> <li>- <b>Q2b</b> Can you tell me about the current state of flexibility in floor design?<br/> Kunt u me vertellen over de huidige staat van flexibiliteit in het ontwerpen van vloeren? <ul style="list-style-type: none"> <li>○ Can you give me an example of ...?</li> <li>○ What is your experience with ...?</li> <li>○ How are flexibility measures included in ...?</li> </ul> </li> <li>- <b>Q2c</b> What trends do you see in the development of <b>[the design of building services/structural design/product development/architecture]</b> that could</li> </ul> |  |
|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|

|                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |         |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
|                                     | <p>influence the design of floor systems? These can be trends related to flexibility, but don't necessarily have to be.</p> <p>Welke trends ziet u in de ontwikkeling van <b>[installatietechniek/het constructief ontwerpen/product ontwikkeling/de architectuur]</b>, die invloed zouden kunnen hebben op het ontwerp van vloersystemen? Deze trends kunnen gerelateerd zijn aan flexibiliteit, maar dat is niet persé nodig.</p> <ul style="list-style-type: none"> <li>○ Can you give me an example of...</li> <li>○ How do you expect ... to evolve?</li> <li>○ How could ... impact the design of floor systems? <i>amount, size, weight, accessibility, type of services</i></li> </ul> <p><u>Topic 3: Opportunities and challenges</u></p> <ul style="list-style-type: none"> <li>- <b>Q3a</b> What opportunities do you see for flexibility with regards to <b>[the design of building services/structural design/product development/architecture]</b> and floor systems?<br/>Welke kansen ziet u voor flexibiliteit met betrekking tot <b>[installatietechniek/het constructief ontwerpen/product ontwikkeling/de architectuur]</b> en vloersystemen? <ul style="list-style-type: none"> <li>○ How can ... be facilitated?</li> <li>○ What opportunity has the most potential according to you?</li> </ul> </li> <li>- <b>Q3b</b> What challenges or obstacles do you foresee for flexibility with regards to <b>[the design of building services/structural design/product development/architecture]</b> and floor systems?<br/>Welke uitdagingen of obstakels voorziet u voor flexibiliteit met betrekking tot <b>[installatietechniek/het constructief ontwerpen/product ontwikkeling/de architectuur]</b> en vloersystemen? <ul style="list-style-type: none"> <li>○ In what way does ... form a(n) challenge/obstacle?</li> <li>○ How could ... be dealt with?</li> </ul> </li> </ul> |         |
| General questions and open dialogue |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 15 min. |
| Closing comments                    | <ul style="list-style-type: none"> <li>- Ask participant if everything was clear</li> <li>- Ask participant if they have anything to add</li> <li>- Expression of gratitude</li> <li>- Confirmation of possible follow-up</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5 min.  |

Table B.2: Interview guide for patrons

| Activity          | Comments/Question                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Approximate Time |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Introduction      | <ul style="list-style-type: none"> <li>- Costumery pleasantries</li> <li>- Introduction of self</li> <li>- Review of interview process               <ul style="list-style-type: none"> <li>o Goals of the interview</li> <li>o Interview method</li> <li>o Audio recording</li> <li>o Use of data and confidentiality</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5 min.           |
| Structured topics | <p><u>Topic 1: Flexibility of buildings</u></p> <ul style="list-style-type: none"> <li>- <b>Q1a</b> Can you tell me about developments in the building industry that are of interest to you or your field?<br/>Kunt u me vertellen over ontwikkelingen in de bouw die van interesse zijn voor u of uw vakgebied?               <ul style="list-style-type: none"> <li>o Can you give me an example of ...?</li> <li>o What is your experience with ...?</li> <li>o Why is ... interesting to [domain]?</li> </ul> </li> <li>- <b>Q1b</b> Can you tell me how flexible or adaptable buildings are viewed in your field?<br/>Kunt u mij vertellen hoe er vanuit uw vakgebied naar flexibele of aanpasbare gebouwen gekeken wordt?               <ul style="list-style-type: none"> <li>o Can you give me an example of ...?</li> <li>o What is your experience with ...?</li> </ul> </li> <li>- <b>Q1c</b> In my research I define flexibility as “the capacity of an object to adapt to changing circumstances and requirements without the need for intrusive intervention”. What would be an “intrusive intervention” to you?<br/>In mijn onderzoek definieer ik flexibiliteit als “het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen zonder de noodzaak voor een ingrijpende ingreep”. Wat zou voor u een “ingrijpende ingreep” zijn?               <ul style="list-style-type: none"> <li>o Would ... be too intrusive?</li> <li>o What hindrance would you expect in case of ...?</li> <li>o How often (time period) would you be ok with ...?</li> </ul> </li> </ul> <p><u>Topic 2: Flexibility of floors</u></p> <ul style="list-style-type: none"> <li>- <i>Introduce flexibility of floors, use a summary of the answers of the designers to the question on what floors are to provide an idea of what a floor does and what flexibility of these things can add.</i></li> <li>- <b>Q2a</b> How can flexibility of floors be of added value to you?</li> </ul> | 40 min.          |

|                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |         |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
|                                     | <p>Hoe kan flexibiliteit van vloeren een toegevoegde waarde voor u zijn?</p> <ul style="list-style-type: none"> <li>○ Flexibility of what characteristic/function of a floor would interest you most?</li> <li>○ Can you give me an example of ...?</li> <li>○ How can ... be of added value?</li> </ul> <p><u>Topic 3: Incentives and obstacles</u></p> <ul style="list-style-type: none"> <li>- <b>Q3a</b> What incentives are needed to include flexible structures in (investment)policies?<br/>Welke prikkels zijn er nodig om flexibele bouw op te nemen in het (investerings)beleid? <ul style="list-style-type: none"> <li>○ Can you give me an example of ...?</li> <li>○ Is ... essential?</li> <li>○ How do you think ... can be realised?</li> </ul> </li> <li>- <b>Q3b</b> What opportunities do you see for [investments in/policies on] flexible structures?<br/>Welke kansen ziet u voor [investerings in/beleid voor] flexibele bouw? <ul style="list-style-type: none"> <li>○ Can you give me an example of ...?</li> <li>○ How can ... be facilitated?</li> <li>○ What opportunity has the most potential according to you?</li> </ul> </li> <li>- <b>Q23c</b> What challenges or obstacles do you see for [investments in/policies on] flexible structures?<br/>Welke uitdagingen of obstakels voorziet u voor [investerings in/beleid] voor flexibele bouw? <ul style="list-style-type: none"> <li>○ In what way does ... form a(n) challenge/obstacle?</li> <li>○ How could ... be dealt with?</li> <li>○ Is ... a deal-breaker?</li> </ul> </li> </ul> |         |
| General questions and open dialogue |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 15 min. |
| Closing comments                    | <ul style="list-style-type: none"> <li>- Ask participant if everything was clear</li> <li>- Ask participant if they have anything to add</li> <li>- Expression of gratitude</li> <li>- Confirmation of possible follow-up</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 5 min.  |

## B.2 Information sheet informed consent form

This information sheet provides an overview of the purpose and procedure of the interview and what it means to partake. If the participant has any remaining questions after reading the information sheet, the researcher can be contacted for answers.

### Purpose of the research

The purpose of the research is to explore the possibilities and challenges of implementing flexibility measures in floor design. Here, flexibility indicates the capacity of the floor to adapt to changing circumstances and requirements without the need for intrusive intervention and is intended as a means

to contribute to the circularity of the floor. The aim of the interview is to gain insight into the perspective of the participant on this topic, to review the current state of affairs and developments regarding flexibility in their field of expertise, and to explore the possible future developments that could affect, hinder, or benefit flexible design.

### Benefits and risks of participating

To prevent a further depletion of natural resources and reduce the current strain on the environment, a shift towards a more circular economy is imperative. The construction industry has an integral role in this development, as becomes apparent by its position as one of the five main priorities of the Dutch government in the transition towards a circular economy. Participation in this interview helps further the research on improving the circularity of buildings components in the construction industry.

The risk associated with the interview is the leakage of personal data, such as name and organisation. To minimise this risk, all data collected, through notes and audio recordings, will be anonymised and only anonymous data will be used in the report. All data will be stored on a secured server with two-step verification.

### Procedures for withdrawal from the study

The participant can decide to withdraw from the study, both before and after the interview has taken place. This can be done by contacting the researcher and clearly stating that the participant no longer wants to partake in the study. In case the participant decides to withdraw after the interview has taken place, the records of the interview will be erased.

### Usage of (personal) data

The interview will be recorded using both audio recordings and written notes. These recordings will be transcribed into written text for use in the report. The audio recordings and written notes will be anonymised, and any personal information will be removed from the transcription. Only anonymous data will be used in the report. The recorded data will be stored on a secured server with two-step verification. The participant has the right to request access to and rectification or erasure of personal data.

### Retention period for research data

Both the audio recordings and written notes will be erased when the research is completed and the final report has been submitted. The anonymised transcription of the interview will be part of the final report and will thus not be deleted.

### Contact details

Any remaining questions or remarks can be directed at the researcher:

Name: L.I. (Lisa) van Iperen  
 Telephone: (+31) (0)6 18665089  
 E-mail: [l.i.vaniperen@student.tudelft.nl](mailto:l.i.vaniperen@student.tudelft.nl)

In case contact with the research institute is desired, the research supervisor can be contacted:

Name: H.R. (Roel) Schipper  
 Telephone: (+31) (0)152789933  
 E-mail: [h.r.schipper@tudelft.nl](mailto:h.r.schipper@tudelft.nl)

## B.3 Informed consent form

*Please tick the appropriate boxes*

**Yes No**

### Taking part in the study

I have read and understood the study information dated 13/01/2021, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

☐ ☐

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

☐ ☐

I understand that taking part in the study involves an interview which is recorded by both audio recordings and written notes, that the interview will be transcribed as anonymous text for inclusion in the report, and that the audio recordings and written notes will be destroyed when the research is completed. ☐ ☐

#### Risks associated with participating in the study

I understand that taking part in the study involves the risk of leaking of personal data. ☐ ☐

#### Use of the information in the study

I understand that information I provide will be used for a research report. ☐ ☐

I understand that personal information collected about me that can identify me, such as name and organisation, will not be shared beyond the study team. ☐ ☐

I agree that my information can be quoted in research outputs. ☐ ☐

#### Future use and reuse of the information by others

I give permission for the anonymised transcription of my interview to be archived in the 4TU.Centre for Research Data repository so it can be used for future research and learning. ☐ ☐

#### Signatures

\_\_\_\_\_  
Name of participant [printed]                      Signature                      Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

\_\_\_\_\_  
Lisa van Iperen                      Signature                      Date

Study contact details for further information:

Name: L.I. (Lisa) van Iperen  
Telephone: (+31) (0)6 18665089  
E-mail: [l.i.vaniperen@student.tudelft.nl](mailto:l.i.vaniperen@student.tudelft.nl)

## B.4 Interview transcription and coding

In Table B.4 up to Table B.13, the verbatim transcription of the interviews can be found. The thematic coding is included in these transcriptions, the colours used for the thematic coding can be found in Table B.3. All interviews were done by the author of this thesis and the interviews are presented in the language spoken during the interview.

Table B.3: Colour codes used for the thematic coding of the interviews

| Developments     | Flexibility in the building industry | Experiences with flexibility        |
|------------------|--------------------------------------|-------------------------------------|
| Weight reduction | Not considered (sufficiently)        | Experience based problem prevention |
| Standardisation  | Office buildings                     | Universal design                    |
| Demountability   | Popular theme                        | Column structure                    |
| Digitalisation   | Life-time proof                      | Overcapacity                        |
| Life-time proof  | Flex housing                         | Independence of systems             |



|                         |
|-------------------------|
| Timber                  |
| Lack of skilled workers |
| Sustainability          |
| Building physics        |
| Modularity              |
| Future proof            |
| Legislation change      |
| Wireless network        |

|                      |
|----------------------|
| Rearrangeable layout |
|----------------------|

|                             |
|-----------------------------|
| Products                    |
| Flexibility in design stage |

|                               |
|-------------------------------|
| <b>Intrusive intervention</b> |
| Costs                         |
| Function                      |
| Structure                     |
| Damaging operation            |
| Depends on situation          |
| Time                          |
| Value                         |

|                      |
|----------------------|
| <b>Floor</b>         |
| Horizontal plane     |
| Load-bearing element |
| Stabilising element  |
| Partitioning element |
| To stand on          |
| Building services    |
| Aesthetics           |

|                   |
|-------------------|
| <b>Incentives</b> |
| Pioneers          |
| Financial         |
| Government        |
| Score             |
| Supply            |

|                           |
|---------------------------|
| <b>Design suggestions</b> |
|---------------------------|

|                                    |
|------------------------------------|
| <b>Chances</b>                     |
| Residual value                     |
| Process independence               |
| Facilitating changing requirements |
| Cost of failure                    |
| Professional investors             |
| Sustainability                     |
| Future proof                       |
| Standardisation                    |
| Permit free adaptation             |

|                            |
|----------------------------|
| <b>Obstacles</b>           |
| Costs                      |
| Height                     |
| Awareness                  |
| Ownership                  |
| Integration of disciplines |
| Legislation                |
| Conservative industry      |

Table B.4: Transcription interview P1

|                                       |                             |                                                                                                                                                                                                                                                                                            |
|---------------------------------------|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Interviewee</b>                    | P1                          | Structural engineer at a large Dutch construction firm                                                                                                                                                                                                                                     |
| <b>Date and time</b>                  | March 11 <sup>th</sup> 2021 | 16:30                                                                                                                                                                                                                                                                                      |
| <b>Topic 1: Flexibility of design</b> |                             |                                                                                                                                                                                                                                                                                            |
| <b>Q1a</b>                            | <b>I</b>                    | De eerste vraag die ik graag wil stellen is: Kun je mij vertellen over de huidige staat van flexibiliteit in het constructief ontwerpen?                                                                                                                                                   |
|                                       | <b>P1</b>                   | Of ik daar iets over kan vertellen. De flexibiliteit in relatie tot?                                                                                                                                                                                                                       |
|                                       | <b>I</b>                    | Constructief design in het algemeen, constructeurschap.                                                                                                                                                                                                                                    |
|                                       | <b>P1</b>                   | Wat ik daarover kan vertellen. Ik denk dat dat vaak conflictsituaties zijn, waarbij er dingen gewenst worden die vaak best wel lastig zijn om constructief op te lossen. Meestal is het dan heel halsstarrig, vind ik. Van 'nee, het gat moet erin, je ziet maar een oplossing te vinden'. |
|                                       | <b>I</b>                    | Dat gat heeft dan te maken met flexibiliteit van het product of met hoe mensen met een opdracht om gaan?                                                                                                                                                                                   |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | P1 | Nou dat heeft ermee te maken dat het ontwerp niet zo flexibel is. Er zijn wensen. En dat is ook logisch natuurlijk, er is een programma van eisen en een programma van wensen en dat zal ook gerealiseerd moeten worden. Maar dan is het ook vaak zo, net als dat je ziet bij [projectnaam], dat er een systeem gekozen wordt, bijvoorbeeld van vloeren die voorgespannen zijn, die helemaal niet afgestemd zijn op de gewenste flexibiliteit voor allerlei leidingen en doorvoeren die er in het gebouw gewenst zijn. En dat komt er dan in een veel te laat stadium uit, vind ik. |
|     | I  | En dan kan dat niet meer aangepast worden? Of met moeite.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P1 | Dan is het al gepasseerd, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | I  | Dus eigenlijk zeg je: De huidige staat van flexibiliteit is niet heel best?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q1b | P1 | Nee die is ver te zoeken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Dan gaan we hem iets persoonlijker trekken met de tweede vraag. Hoe neem je zelf flexibiliteit mee in je werk, of neem je dit überhaupt mee?                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P1 | Ik ben geen ontwerpend constructeur. Dus niet echt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | I  | Dus flexibiliteit is niet iets was aan bod komt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P1 | Nou ja, als je flexibiliteit wilt zien als hoe je jezelf opstelt. Dan is het wel, dan ben ik wel flexibel in de zin dat je zegt: Ik ben ten alle tijden bereid om een oplossing te vinden en ook naast de gebaande paden even te kijken van wat kunnen we daar nog aan doen. Dat vind ik ook flexibiliteit.                                                                                                                                                                                                                                                                         |
|     | I  | Dat is zeker waar. Maar niet dat je in het constructeursproces oplossingen meeneemt omdat je weet dat het de flexibiliteit ten goede zou kunnen komen?                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P1 | Jawel, uit ervaring in het verleden heb je natuurlijk momenten dat je zegt van 'o daar heb je weer zo iets, we zullen wel alvast maar die kant op gaan'.                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | I  | Kun je daar een voorbeeld van noemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P1 | Kun je daar een voorbeeld van noemen? Nee zo gauw niet. Maar ik heb wel, bijvoorbeeld bij [projectnaam], dat je daar de les uit moet trekken dat je zegt van: ik heb hier een systeem, daar zitten strengen in, en dat is het gegeven dat je, hoe zou ik het zeggen, dat je ze voor moet zijn, en nu proberen jullie je leidingen er maar tussen te leggen en niet andersom, want dat is, ik vind dat de omgekeerde wereld.                                                                                                                                                         |
| Q1c | I  | Ja, je zegt het is omgekeerde wereld dat jij je moet aanpassen aan de leidingen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P1 | Ja, juist.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | Oké. Wat zijn de ontwikkelingen, de huidige ontwikkelingen, op het gebied van flexibiliteit binnen het constructeursschap? <i>[na een korte stilte]</i> Zijn er ontwikkelingen? Dat is misschien een concretere vraag in dit opzicht.                                                                                                                                                                                                                                                                                                                                               |
|     | P1 | Zijn er ontwikkelingen in de flexibiliteit binnen het constructeursschap?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Ja, in de zin van, misschien niet iets wat nu al gebeurt, maar zie je iets dat verandert in het constructeursschap ten opzichte van flexibiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P1 | Nee, ik denk dat dat meer in een soort productontwikkeling zit. Van bijvoorbeeld de leidingvloer. Maar dan bedenk ik me wel, de leidingvloer geeft dus een middel van ik heb een gebiedje waarin ik lekker leidingen kan lopen maken, binnen bepaalde randvoorwaarden. Dus dat is het product. Alleen jouw, van tevoren, de beschrijving, de flexibiliteit, is dat ook niet een flexibiliteit voor het totale gebouw, want vervolgens stort je hem weer helemaal vol en ben je niet meer flexibel.                                                                                  |
|     | I  | Nee zolang je mortel gebruikt ben je niet meer flexibel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P1 | Nee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | I  | Nee. Dus je geeft aan dat de ontwikkelingen van flexibiliteit meet op de productontwikkelingshoek zit dan in de constructeurhoek, in dat opzicht.                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P1 | Ja. En ik denk dat je dan in het voortraject moet zitten of bij een prefabbeton fabriek die een product in de markt wil zetten, maar niet als je zegt van het gebouw is al ontworpen, de grote lijnen bepaald, dan kun je op dat moment niet nog eens aan de gang met zal ik eens heel flexibel gaan doen. Want over zes weken moet het pakketje klaar zijn om het te gaan bouwen.                                                                                                                                                                                                  |
|     | I  | Ja. En als zo'n producent met een nieuw product komt. Hoe, een andere vorm van flexibel, hoe flexibel ben jij, of zijn jullie, er dan in om die andere vloer dan te gaan gebruiken in het gebouw?                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P1 | Natuurlijk, dat maakt niet uit. Dan ben ik heel flexibel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Als iemand zegt: ik wil graag deze vloer. Dan zeg jij: prima, dat gaan wij doorrekenen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

|                                       |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
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|                                       | P1 | Ja. Maar dan is het product ook waarschijnlijk al zover ontwikkeld, of je moet in die ontwikkeling meelopen. Dat is ook leuk. Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Q1d                                   | I  | Nou, zoals ik al aangaf, definieer ik flexibiliteit in mijn onderzoek als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen zonder de noodzaak voor een ingrijpende ingreep. Waar zou jij de lijn trekken voor ingrijpende ingreep?                                                                                                                                                                                                                                                                                                                      |
|                                       | P1 | Ja dat weet ik niet. Bij mij schiet er, ja, ik vind het een moeilijk te pinpointen vraag. Bij mij schiet te binnen van dat je ook niet zo ver moet gaan dat je zegt van ik heb een vloer of een wand en dan moet ik ergens gebieden in hebben waar ik over veertig jaar, want wie weet wat we dan allemaal in de vloer of muur duwen, hoewel dat ook minder kan worden hè, met alle draadloze toestanden, alleen het riool is dan een beetje moeilijk. Dat je niet zover moet gaan dat dat een hele moeilijke leidende factor zou worden, terwijl het misschien helemaal niet gebruikt zou worden. |
|                                       | I  | Nee oké. Maar ik bedoel in de zin van zou je bijvoorbeeld, als ik het heb over ik mag geen ingrijpende ingreep doen maar ik wil het wel kunnen aanpassen. Zou jij het opzagen van een vloer ingrijpend vinden of trek je de lijn bij het losschroeven van vloerpanelen, is dat al ingrijpend?                                                                                                                                                                                                                                                                                                      |
|                                       | P1 | Het één is ingrijpender als het andere. Maar als je zegt van daar moet een leiding door en we hebben gekeken wat daar ligt, zaag er vrolijk een stuk uit. Dat is geheel aan, wat mag het economisch kosten. Daar hangen dan ook weer kosten aan vast. Dus wat zijn die kosten? Of gooi ik het weg en doe er een nieuwe vloer in.                                                                                                                                                                                                                                                                   |
|                                       | I  | Maar dat willen we dus voorkomen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P1 | Ja, jij! [gelach]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | I  | Ja dat wil ik voorkomen!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                       | P1 | Nee, wij met zijn allen. Daar ben ik het ook mee eens, natuurlijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                       | I  | Stel je hebt een vloer, even al het geld ter zijden, we hebben oneindig veel geld en het kan allemaal. Je hebt een vloer en je wil iets aanpassen, hoever zou je willen gaan in het aanpassen van de vloer voordat je denkt 'nee dit is echt te veel moeite, dit veroorzaakt overlast'?                                                                                                                                                                                                                                                                                                            |
|                                       | P1 | Maar als je iets aan wil passen, dan ben je er al in aan het zagen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | I  | Maar dat hoeft niet bij alle vloerconcepten. Er zijn bijvoorbeeld ontwerpen met losse vloerplaten aan de bovenkant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | P1 | Een soort computervloeren. Nou ja, daar zou je, dan zou je al zo gebouwd moeten hebben. En dan is het natuurlijk niet ingrijpend. Maar, in welke mate doe je dat? Zeg je van, zijn het gebiedjes of is heel de vloer zo? En dan kom je weer met het probleem, volgens mij, met de geluidseis tussen woningen, dat dan niet meer voldoet. Of je krijgt zulke dikke vloeren [houdt zijn handen een stuk uit elkaar]. Dat vindt de aannemer niet leuk, want dat is duurder. Maar het financiële moest ik... Maar dat speelt toch altijd wel op de achtergrond.                                        |
|                                       | I  | Ja dat klopt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Q2a                                   | I  | We hebben het al een beetje over vloeren gehad, maar de vragen gingen nog niet specifiek over vloeren. Dan wil ik bij het begin van het stukje over vloeren eerst een hele brede vraag stellen. Wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | P1 | Wat betekent een vloer van mij?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | I  | Wat zijn de eigenschappen die een element een vloer maken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | P1 | Dat ie horizontaal is. Dat je eroverheen kunt lopen. Of iets op kunt zetten. Jeetje wat een vraag. Wat is een vloer voor jou? Ja. Een constructief element, die verschillende functies heeft. Het erop kunnen wonen, leven, werken. Het gebouw ook een stabiliserende functie kan geven in het gehele samenspel. Dat is een vloer.                                                                                                                                                                                                                                                                 |
|                                       | I  | Nou dat is een goed constructeurs antwoord voor van een vloer is, denk ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q2b                                   | I  | We hebben het al een beetje gehad, maar ik ga de vraag nog wel even stellen. De vraag is: Kun je me vertellen over de huidige staat van flexibiliteit in het ontwerpen van vloeren? We hebben het al gehad over de leidingvloeren en de computervloeren zijn ook even benoemd. Is dat de extent van flexibiliteit in vloeren op dit moment?                                                                                                                                                                                                                                                        |
|                                       | P1 | Ja en nog het verlaagde plafond. Ja in mijn kennis.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | I  | Ja dit gaat puur om jouw ervaring, jouw kennis.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

|            |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | <b>P1</b> | Leidingvloeren, verlaagd plafond, verhoogde vloer. Ja, dat is het zo'n beetje. Heb jij nog andere concepten dan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|            | <b>I</b>  | Ja ik ben inderdaad de leidingvloer tegengekomen. Je hebt dan ook nog de hollow space vloer. Dan is dan meestal een composiete constructie met een betonplaat en stalen liggers en daar zit dan een ruimte tussen voor leidingen. En inderdaad de verhoogde vloer en het systeemplafondsysteem. Dat zijn een beetje de dingen die ik tegen ben gekomen.<br>Heb je ook ervaring met deze verschillende vloersystemen?                                                                                                                                                                                                                                                                                      |
|            | <b>P1</b> | Nou ja, met een computervloer hoef je niet veel ervaringen te hebben. Het is puur dezelfde constructie, alleen het parket wordt opgehoogd. That's it. Dat heeft weinig invloed. De leidingvloer, bij huidige appartementenbouw wordt die toch al behoorlijk veelvuldig toegepast. En dat is, zoals ik al zei, een combinatie van een beetje flexibel kunnen zijn om toch wat leidingen kwijt te kunnen en toch de vloeren neer te kunnen leggen en niet te hoeven stempelen en de massa te kunnen halen voor het geluid. Dus het is, want het is een combinatie van de eisen waaraan je moet voldoen natuurlijk.                                                                                          |
|            | <b>I</b>  | En als je met zo'n leidingvloer in een appartementengebouw werkt. Is dat dan anders dan als je een traditionele vloer gebruikt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|            | <b>P1</b> | Nee vind ik niet nee. En die vloeren zitten mooi bij de fabrikant om te berekenen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|            | <b>I</b>  | Dus je hoeft alleen de specificaties daarvan mee te nemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|            | <b>P1</b> | Ja. Bijvoorbeeld om te controleren of ze de uitgangspunten goed hebben genomen, zeg maar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Q2c</b> | <b>I</b>  | Deze vraag sluit ook een beetje aan op wat we al besproken hebben. Welke trends zie je in de ontwikkeling op het gebied van constructief ontwerpen, of constructeurerschap, die invloed zou kunnen hebben op het ontwerpen van vloersystemen. Dit hoeft niet persé gerelateerd te zijn aan flexibiliteit, maar trends op het gebied van vloersystemen in het algemeen.                                                                                                                                                                                                                                                                                                                                    |
|            | <b>P1</b> | Trends. Dat is dus trends om aan die flexibiliteit te voldoen. In sommige gevallen ook om aan gewichtsbesparing te voldoen, waar het niet nodig is. Bijvoorbeeld de bollenvloer en de bloempottenvloeren. Trends om sneller te kunnen bouwen, prefab. Alleen dan is het nog geen trend, denk ik, om het weer uit elkaar te kunnen schroeven. Eerlijk gezegd heb ik daar ook mijn twijfels over.                                                                                                                                                                                                                                                                                                           |
|            | <b>I</b>  | Vertel, wat zijn daar de twijfels over?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|            | <b>P1</b> | Nou, stel dat we een gebouw maken dat we uit elkaar kunnen schroeven. Laten we het bij een simpele woning houden. Die kun je ook nog wel makkelijk uit elkaar schroefbaar maken. En over vijftig jaar schroeven we die uit elkaar, wat doen we dan met die wand?                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|            | <b>I</b>  | Als wand hergebruiken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|            | <b>P1</b> | Wat zijn de wensen van de mensen voor een woning over vijftig jaar? Kun je dan echt die wand nog een keer gebruiken? Of voer je hem dan, met alle respect, af naar de derde wereld? En dan moeten ze weer een schip, milieu. Het is moeilijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|            | <b>I</b>  | Ja inderdaad. Dat is natuurlijk ook een beetje het idee achter de flexibiliteit. Dat je nu inderdaad nog niet weet wat er over vijftig jaar in een vloer of in een wand moet zitten. Als je flexibiliteit kan waarborgen kan je dat tegen die tijd nog aanpassen. Dat is inderdaad wel de gedachte erachter. Maar of dat de realiteit is, kunnen we inderdaad dan pas zeggen.                                                                                                                                                                                                                                                                                                                             |
|            | <b>P1</b> | Dus ligt het hergebruik dan niet meer in de, wel het uit elkaar halen, demonteren en delamineren. In bepaalde grondstoffen en die her te gebruiken. Ik denk dat dat reëler is. Maar ook andere dingen. Wat ik bijvoorbeeld vind in de bouw, ik heb dat gemerkt hier met de verbouwing, hoe ontzettend veel er weg wordt gegooit en hoe ontzettend laks er om wordt gegaan met materialen. Ik denk dat daar ook wel een slag in gemaakt kan worden, maar dat heeft niets met flexibiliteit te maken natuurlijk. Maar wel met de belasting van het milieu. [Referentie naar een project] Maar dat is de mentaliteit van de mensen die aan het bouwen zijn. Daar worden ook wel dingen in gedaan natuurlijk. |
|            | <b>I</b>  | Je benoemde net ook dat er een trend is om vloeren lichter te ontwerpen, maar daarvoor hebben we ook al benoemd dat gewicht een uitdaging is voor flexibele vloeren wat akoestiek betreft.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|            | <b>P1</b> | Dat is waar het kan, waar het nodig is. Dus bij een groot kelderdek ofzo. Waar je geen onderling geluid tussen twee woningen te maken hebt. Dan is het wel interessant om die dikke vloer wat lichter te maken, zodat die eventueel nog wat dunner kan doordat die lichter is of minder belasting heeft op de onderconstructie.                                                                                                                                                                                                                                                                                                                                                                           |

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|                                              | I  | Dus een lichte constructie is eigenlijk alleen relevant bij niet bewoonde gedeeltes?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                              | P1 | Wanneer geluid geen issue is natuurlijk. Of dat het geluid naar de andere kant mag. Of je kunt iets loskoppelen op de een of andere manier.                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                              | I  | Nou dat is opzicht best wel een lijst aan ontwikkelingen die er zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                              | P1 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Topic 3: Opportunities and challenges</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Q3a                                          | I  | Dan gaan we door naar het volgende en laatste onderdeel. Het laatste onderdeel is kansen en uitdagingen. En als eerste wil ik vragen: Welke kansen zie je voor flexibiliteit met betrekking tot het constructief ontwerpen van vloersystemen?                                                                                                                                                                                                                                                                                                                                                    |
|                                              | P1 | Positieve kansen. Vanuit de constructie, de constructeur gezien. Wat bij mij dan te binnen schiet, ik denk dat dat gewoon productontwikkeling is. Dat is ook om kansen te creëren. Ik probeer iets te bedenken, te ontwikkelen wat beter is, flexibeler is, wat minder milieubelastend is. Allemaal zaken die spelen nu. En dat dan in de markt zetten. Maar voor mezelf? Nee.                                                                                                                                                                                                                   |
|                                              | I  | En vanuit jouw oogpunt bijvoorbeeld, je had het er net over dat opeens aan het eind leidingen op een andere plek moeten liggen. Als er een flexibel vloersysteem wordt gebruikt, kan het leidingverloop op elk moment in het proces worden aangepast. Zou dit voor jou dan een voordeel zijn, dat je niet afhankelijk bent van wat de leidingmensen op dat moment bedenken?                                                                                                                                                                                                                      |
|                                              | P1 | Natuurlijk, dat maakt het alleen maar simpeler. Nu zit je je een slag in de rondte te rekenen om al die leidingen te kunnen verantwoorden. Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                              | I  | En als je in die categorie denkt, zou je dan ook nog andere kansen kunnen bedenken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                              | P1 | Je kunt het van elkaar loskoppelen. Dan zeg je van hier heb ik mijn constructie pakket en daar heb ik mijn leiding pakket en 'do your thing'. Alleen dan wordt het zo dik en het gebouw wordt zo hoog [houdt zijn handen een stuk uit elkaar]. En dat willen ze niet.                                                                                                                                                                                                                                                                                                                            |
|                                              | I  | Dan ga ik nu gewoon direct door naar de volgende vraag. Dat is: Welke uitdagingen of obstakels voorzie je?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Q3b                                          | P1 | Daar was ik al. Ja, de hoogte, de kosten. Want de gevel wordt ook langer. Dat zijn de twee hoofdzaken denk ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                              | I  | En hoe zouden we daarmee om kunnen gaan? Misschien moeten we de twee problemen even apart nemen. Als je er zo snel even over brainstormt, wat zou een eventuele oplossing voor het hoogte probleem kunnen zijn?                                                                                                                                                                                                                                                                                                                                                                                  |
|                                              | P1 | Een oplossing?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                              | I  | Of een oplossingsrichting, een complete oplossing is natuurlijk wel wat veel gevraagd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | P1 | De hoogte is het gevolg. Dat is een vaststaand feit als je flexibel wil bouwen. Zo simpel is het. In kantoren deed je niet anders. Kanaalplaat, volleggen. Meestal was het dan met een verlaagd plafond. Als je nu kantoorgebouwen ombouwt naar woningen, heb je ook al meer ruimte tot je beschikking, meestal drie meter hoog ofzo. Dus dan is het een bijkomend voordeel dat je die hoogte al hebt. Dan moet je de hoogte gewoon voor lief nemen. En moet de aannemer niet zeuren over de drie lagen stenen die hij neer moet leggen. Maar die zit gewoon te mieren puntje puntje.            |
|                                              | I  | Als men dit echt wil, moet de extra hoogte dus gewoon voor lief genomen worden.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                              | P1 | Of misschien een tussenweg. Of naja tussenweg. Nou je hebt bepaalde factoren. Je hebt elektra, is niet zo dik. Bepaalde leidingen van riool zijn wel significant dik. Dat je zegt, nou die leg ik ergens vast als een hoofdleiding, die dan daar de vloer beïnvloed en niet flexibel is. Maar ik kan er naartoe met allerlei kleine leidingen rond vijftig. En daar kan ik wel flexibel zijn. Alleen die wc blijft op een vaste zitten, de standlijn blijft op een vaste plek liggen. Want dan kom je ook weer aan het verticale deel. Zo zou je een soort semi-flexibiliteit kunnen realiseren. |
|                                              | I  | Een soort poldermodel eigenlijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                              | P1 | Jij zegt het.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                              | I  | Dat is op zich ook nog wel een optie inderdaad. En als we kijken naar het economische probleem? Al is dat natuurlijk sterk gerelateerd aan het hoogte probleem.                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                              | P1 | Het hoogte probleem en eigenlijk een extra vloer komt erin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                              | I  | Dan kun je dat eigenlijk voornamelijk oplossen door goedkopere materialen te gebruiken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                              | P1 | Ja. Maar goed, die constructieve vloer, die wordt misschien ook wel iets goedkoper, want dat is een simpele vloer. Daar zitten niet zoveel engineerings- en productiekosten                                                                                                                                                                                                                                                                                                                                                                                                                      |

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|  |  | aan, dus die wordt goedkoper per vierkante meter. Het is plussen en minnen. Maar ja uiteindelijk resulteert dat in een prijs voor een appartementje en die kunnen we nu al niet betalen. |
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Table B.5: Transcription interview P2

|                                       |                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
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| <b>Interviewee</b>                    | P2                          | Project developer at a large Dutch construction firm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Date and time</b>                  | March 18 <sup>th</sup> 2021 | 10:00                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Discussion beforehand</b>          |                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | <b>P2</b>                   | Ik heb een voorkeur voor de transitie van de lineaire en circulaire economie, dus ik zal ook heel veel dingen proberen altijd op hoog over niveau te belichten. Omdat daar veel meer de keuzes vandaan moeten gaan komen. De overheid die focust heel erg op de bouw, omdat dat natuurlijk een hele makkelijke is. Maar die is eigenlijk al vrij circulair ingestoken, in dat opzicht, als je kijkt naar de basis van waar we circulariteit en de definitie wat circulariteit nou eigenlijk betekent. Dus zo kijk ik er heel erg naar, maar brand los!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Topic 1: Flexibility of design</b> |                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Q1a</b>                            | <b>I</b>                    | De eerste vraag is: Kun je me iets vertellen over de ontwikkelingen in de bouw die van interesse zijn voor jou of je vakgebied? Dit gaat niet specifiek over flexibiliteit, maar opvallende of interessante ontwikkelingen in het algemeen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | <b>P2</b>                   | De grootste ontwikkeling die je nu ziet, en dat is natuurlijk ook wat het meeste het nieuws haalt, is dat we natuurlijk opeens heel erg gaan denken in prefab en compleet 100% prefab uit de fabrieken. Dat speelde altijd al in de deelelementen. En nu is het totaal, nou [bedrijf waarvoor P2 werkt] is natuurlijk een goed voorbeeld, maar je hebt ook een [middelgroot bouwbedrijf] en, [bedrijf waarvoor P2 werkt] was natuurlijk ook niet de eerste, je hebt [grote aannemer] gehad met zijn [project voor rijwoningen uit een fabriek], [groot bouwbedrijf] is natuurlijk heel groot. Iedereen is er nu mee bezig om te standaardiseren in de woningbouw. Het valt eigenlijk nog wel tegen in de u-bouw [utiliteitsbouw], daar wordt veel minder nog op die manier gedacht. Maar het standaardiseren en het denken in prefab elementen, dat begint nu echt door te komen, in de woningbouw. Een andere is, toch wel ook, dat het parametrisch ontwerpen begin nu ook een beetje los te komen, dus dat we toch de combinatie zoeken met de data. Die begint door te komen. En je begint daardoor, nou eigenlijk net als overal in de samenleving, beginnen we kloven te krijgen van wie mee kan met die nieuwe ontwikkelingen. Het is natuurlijk heel technisch, en je krijgt een hele andere koppeling met buiten, met de bedrijven die eigenlijk nog heel traditioneel werken. Je begint een kloof te krijgen, ook in de bouwsector, wie wel en niet mee kan. Dat heeft ook te maken met allerlei regelgeving waar we mee geconfronteerd worden. Dat zijn de grotere ontwikkelingen. Dus de ene is positief, maar er zit ook wel een negatieve component in, dat heel veel mensen in de bouw werkzaam zijn, die waarschijnlijk moeite zullen hebben om mee te kunnen in de nieuwe ontwikkelingen. Voor veel mensen is namelijk een mobiel al een uitdaging. Nou laat staan als je straks met een tablet rond moet lopen op de bouw, want ja alles wordt geacht om daarin te worden opgeslagen en daarin te worden verwerkt. Je hebt natuurlijk een grote groep die gewoon traditioneel werkt met een tekening, een papieren tekening die ze kunnen lezen. Er gaan wat dingen veranderen en we gaan het anders organiseren. Maar dat het anders wordt, zeker voor de woningbouw, dat is natuur wel duidelijk. Daar zijn wij natuurlijk heel erg actief in. |
|                                       | <b>I</b>                    | En wat is het effect van deze ontwikkelingen op jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | <b>P2</b>                   | Nou ja, heel veel dingen worden eigenlijk, heel veel van onze werkzaamheden gaan weg. Want ik hoef hele ontwerpfasen, die ik normaal moet doorlopen, die hoef ik bij heel veel producten, als die gestandaardiseerd zijn, hoef ik niet meer. Want ik heb een catalogus. We gaan gewoon naar catalogus woningen bijvoorbeeld. Bij [bedrijf waarvoor hij werkt] zie je dat dan terug, we hebben [project voor geprefabriceerde woningen] en [project voor geprefabriceerde woningen] is nu voornamelijk nog wonen maar wordt straks natuurlijk uitgebreid. Dan hebben we [project voor woningen uit prefab basiscomponenten], [project voor woningen uit prefab basiscomponenten] is dan ook weer gestandaardiseerd binnen de regio's. En [project voor niet gestandaardiseerde woningen] is, ja dat past eigenlijk, wat we willen maken past nergens in, kunnen we niet echt standaardiseren, en dan gaan we [project voor niet gestandaardiseerde woningen].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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|     |    | <p>[Project voor niet gestandaardiseerde woningen] komen we nog wel veel tegen, natuurlijk, binnenstedelijk waar allemaal maatwerkoplossingen zijn. Hoe verder je gaat in dat proces en je kijkt ernaar, hoe minder er gestandaardiseerd is en hoe meer activiteiten er nog moeten worden uitgevoerd door ons. Maar bij [project voor geprefabriceerde woningen] zijn onze activiteiten echt heel erg aan de voorkant en heel beperkt want dan is de ontwikkeling draait meer gemeente maar het product ligt klaar op de plank. Alles is daarvoor beschikbaar, daar hoeven wij niets meer aan te doen. Dus in dat opzicht, zullen daar nog meer veranderingen gaan optreden want we krijgen gewoon, ja. De verwachting is dat het standaardiseren namelijk een steeds grotere vlucht neemt want [project voor geprefabriceerde woningen] is nu nog beperkt soms in hun ruimte, maar ze moeten opstarten. Het moment dat ze dat goed hebben draaien, zullen zijn ook steeds flexibeler worden in hun systeem. Als de basis eerst maar eens in de fabriek draait. Dus dan wordt het toch anders ontwerpen en dan wordt het een combinatie van [Project voor niet gestandaardiseerde woningen] ook een combinatie wordt van elementen en puzzelen en dan wordt het werk voor ons heel eenvoudig in dat opzicht. En deze lijn zal ook doorgetrokken worden naar kantoren bijvoorbeeld of andere U-bouw elementen. Want ook daar is behoefte, sowieso krijgen we daar nog een verandering natuurlijk. Door Corona zullen er dingen in grotere lijnen gaan veranderen. Winkelgebied zal heel veel gaan veranderen, maar ook in kantoren. Het hybride werken zal nu echt gaan doorbreken, althans, is doorgebroken. Dat zorgt weer voor een hele andere kijk op kantoren, waarvoor kom ik op kantoor, wat doen we op kantoor. En dat vraagt een hele andere indeling. Dat zijn ook grote ontwikkelingen die daarmee samenhangen, die altijd al in de pijplijn zaten, maar nu in een versnelling komen.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Q1b | I  | Oké. Mijn volgende vraag is: Kun je mij vertellen hoe er vanuit jouw vakgebied naar flexibele of aanpasbare gebouwen wordt gekeken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P2 | <p>Eigenlijk heel weinig, bijna niet. En dat heeft meer te maken met de structuur hoe wij ook gewend zijn te werken in Nederland. Als je flexibeler zou willen zijn dan zou je heel anders ernaar kijken. Dan zou je bijvoorbeeld veel meer denken in vloeren en kolommen en wij denken altijd nog steeds gewoon in vloeren en schijven. Bij kantoren denken we natuurlijk veel flexibeler, want daar hebben we wel de vaste stramien en denken we veel meer in kolommen structuren. In de woningbouw, dat is het. Het ene hangt dan weer met het andere samen. Maar als jouw doelgroep particulier is, dan gaat een gebouw eigenlijk, als het een beetje groot is, ook nooit meer tegen de vlakte, want dat is bijna niet te organiseren. En de indeling verandert bijna ook nooit. Het is nooit zo van ik koop mijn buurman erbij en ik breek door, dat gebeurt zelden tot nooit. Als we kijken naar bijvoorbeeld coöperaties, daar is de kans dat het gesloopt wordt of dat ze iets gaan opzetten, of bij beleggers, bij particuliere beleggers minder weer, en industriële beleggers ook weer wat minder, die zitten natuurlijk anders erin, dan verkopen ze het liever. Daar kan nog wel eens wat gebeuren, maar ook bijna niet. Flexibiliteit is ook heel beperkt, wat gevraagd wordt. De voorgevel hoeft je niet te veranderen, dus waar gaan we het vaak in zien? Dat is de kap, dat er mensen daar nog uitbreiding willen hebben, en aan de achterkant van de woning. Maar ja vanuit de overheid wordt dat alleen maar tot de begane grond eigenlijk gefaciliteerd, want uitbreidingen op de verdiepingen dat zit er niet zo niet zo in bij de overheid voor de regelgeving voor vergunningsvrij bouwen. Dus dat is ook beperkt tot de begane grond, dus wat houdt je dan over? Ja dat is de achterpui, dat je die eruit kan halen als element en vier meter verder kan zetten en een uitbouw kan realiseren. Dus flexibiliteit, is altijd zo grappig, daar worden we heel erg op beoordeeld door de gemeente bijvoorbeeld in tender, maar in de praktijk is er niet zoveel vraag naar. Waar wel vraag naar is, is een bepaalde aanpasbaarheid soms op woningniveau. En dan vinden bijvoorbeeld mensen een jaren 30 huis of een vooroorlogs huis weer prettig, want dan heb je houten vloeren en dan kun je lekker makkelijk alles aanpassen zonder gedoe. Want een betonvloer is heel fijn, maar het is natuurlijk ook wel een crime als je die moet aanpassen. Dat is natuurlijk minder makkelijk. Maar in woningbouw moet je natuurlijk onderscheid maken tussen de woningen en een woongebouw. Ja in een woongebouw heb je natuurlijk hele andere eisen, dan is een vloer opeens woning scheidend en niet alleen ruimte delend.</p> |

Table B.6: Transcription interview P3

|                                       |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                             |
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| <b>Interviewee</b>                    |           | P3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Structural engineer and product developer at a small Dutch engineering firm |
| <b>Date and time</b>                  |           | March 24 <sup>th</sup> 2021                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 15:00                                                                       |
| <b>Topic 1: Flexibility of design</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                             |
| <b>Q1a</b>                            | <b>I</b>  | Kun je mij iets vertellen over de huidige staat van flexibiliteit in jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                             |
|                                       | <b>P3</b> | En dan toegespitst op die installaties in de vloer?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                             |
|                                       | <b>I</b>  | Dat hoeft nog niet. Nu hebben we het over het topic algemene verkenning, zal ik maar zeggen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |
|                                       | <b>P3</b> | Zo, dat is een hele open vraag. Dan kan ik wel een heel college gaan voorbereiden. Wat is de definitie van flexibel? Had je die meegestuurd?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |
|                                       | <b>I</b>  | Ja die staat wel ergens hoor. Maar ik verwacht niet dat je die uit je hoofd geleerd hebt. Flexibiliteit is het vermogen van een object, dus dit geval een bouwcomponent of bouwcomponenten, om zich aan te passen aan veranderende omstandigheden en eisen, zonder dat hier een ingrijpende ingreep voor nodig is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                             |
|                                       | <b>P3</b> | Ja, maar betekent dat ook dat het niet tot significant veel meer kosten mag leiden?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                             |
|                                       | <b>I</b>  | Kosten is niet iets wat ik expliciet meeneem in mijn studie of definitie. Dus wat dat betreft niet. Maar snap wel dat dit natuurlijk altijd het kader is waarin we opereren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |
|                                       | <b>P3</b> | Naja, ik vertel het hierom. Wij zijn, ik denk misschien wel vijftien jaar geleden, met een vooruitstrevend concept bezig geweest van Prefab Beton Limburg. Dat waren breedplaatvloeren met ingestorte IPE's. Ken je die of niet?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                             |
|                                       | <b>I</b>  | Ja, de Slimline vloer of zoiets?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                             |
|                                       | <b>P3</b> | Ja daarmee zijn we bezig geweest. Ger van der Zanden moet je anders maar eens benaderen. Dat was voor woningen in [grote Nederlandse stad] met een aantal keuze kopers varianten. En na een half jaar verkennen en daar een bijpassend skelet, voor rekening van de aannemer, die dat graag binnenhaalde dat project, dat traject te hebben doorlopen, projectbezoeken, waren die woningen 30 000 euro per stuk te duur voor de [stadse] markt en hebben we uiteindelijk in kanaalplaten en kalkzandsteen dat project gerealiseerd. De enthousiaste Ger van der Zanden begon met 70 euro per vierkante meter franco werk en tegen de tijd dat we ze bijna moesten gaan inkopen was het 140 euro geworden. Dus ja, wat heb je er dan voor over. Kijk als je steeds wisselende gebruikers van een kantoor hebt, kan ik me er alles bij voorstellen. Misschien ook bij een ziekenhuis of een oudere zorg gebouw. Maar niet voor woningbouw in het segment waar mensen, toen nog, net voorbij een gemiddelde middenwoning in een rij konden kopen. Een soort hybride oplossing, ik weet niet of je de leidingplaatvloeren van VBI kent, heel basaal een kanaalplaatvloer. Is dat je de leidingsleuven niet vult met Spramex beton maar dat je ze met zand vult en dan een cementdekvloer eroverheen legt. Ik weet niet of je die oplossing kende? |                                                                             |
|                                       | <b>I</b>  | Ik ken deze oplossing niet expliciet, maar ik kan me er wat bij voorstellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                             |
|                                       | <b>P3</b> | Naja goed. Een stapje verder is denk ik. Wij passen een inbreiding in oude ruimtes van een fabriek van, kijken hoor, chemisch bedrijf in [grote Nederlandse stad] en die gebouwen staan leeg en dat industriepark [naam]. Dat moet je anders maar even opzoeken. En dat wordt nu het meest duurzame industriecomplex, kantoorverhuur. En dat zijn allemaal hele grote betonnen spanten en daar hangen we spanten tussen om, soms twee lagen, in staalplaatbetonvloer toe te voegen. En niet alleen om de kilo's ijzer maar ook vanwege het doorvoeren van kanalen door de driehoeken in de vakwerkspanten, maken we eigenlijk een heel fragiel vakwerkspant met daarop die staalplaatbetonvloer. Nou dan kan je ten alle tijden dat raster veranderen en in zo'n staalplaatbetonvloer kun je nog wel flink boren voordat hij zegt van nou heb je alle reserves opgesoupeerd. Is dat dan flexibel? Past dat binnen jouw kaders? Dat is voor mij lastig. Ja als ik denk aan flexibel, denk ik dan meer aan een demontabel staalskelet of denk ik dan meer aan hout en dan denk ik niet aan balklagen, dan denk ik aan CLT vloeren of ik denk aan Kerto-Ripa. Ik weet niet of dat je wat zegt?                                                                                                                                                   |                                                                             |
|                                       | <b>I</b>  | Niet direct, nee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                             |
|                                       | <b>P3</b> | Nou Kerto is een hoogwaardig kruisverlijming voor, dat is de Kerto-Q, de bovenplaat, en soms de onderplaat als je H-vormige doorsneden wilt. Dan noemen ze het Kerto-Ripa Box en in het andere geval Ripa-T. En de dragers zijn eigenlijk in één richting georiënteerd, verlijmd. Alleen dan moet je denken aan lamellen van drie vier millimeter,                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                             |

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|    | <p>ten opzichte van, bij gelamineerd hout, twintig dertig veertig millimeter dik, waardoor de foutvrijheid veel geringer is, waardoor je dus een veel hogere buig-trek sterkte mag inbrengen en waardoor ook blijkt dat je E-modulus soms tot 50% hoger ligt. En, naja, dan kan je op strategische plaatsen heel veel voorbedachte sparingen in opnemen en kun je dus leidingen doorvoeren. En de samenwerking van de bovenplaat en de ribben betekent natuurlijk dat je een veel stijvere doorsnede hebt, dat is verlijmt, voor de koppen komt een vijftwintig millimeter dikke plaat, die is ook verlijmt en verschroefd met de koppen van de liggers. Dus dat betekent eigenlijk, als je een hoofdligger hebt en je doet er een kopschot tegenaan en je doet een malletje met schroefgaatjes. Dan schroef je het aan elkaar, dus is het in die zin ook verregaand demontabel. Maar dan heb je het ook gauw over vloersystemen die tussen de 70 en 150 euro kosten. Terwijl een kanaalplaat kost, aangebracht in het werk, ik noem wat, 70 euro. En, ja, een breedplaatvloer, die is het minst flexibel denk ik, hè?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Dat denk ik ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| P3 | <p>Daar kun je natuurlijk wel rioleringsbuizen met bochtstukken en schroefdeksels in mee storten, hè. Dan zou je jezelf ook helpen flexibel te zijn. Maar als je bijvoorbeeld op YouTube naar een filmpje zou zoeken en dat is [project van bedrijf van P3]. Daar zijn wij adviseur en coördinerend constructeur geweest van het [project in grote Nederlandse stad]. Zegt je dat iets?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| I  | Nee, niet zo één twee drie.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| P3 | <p>Dat geeft ook niet. Het is landelijk bekend. Het filmpje staat op onze website. En het is een vijf lagen tellende school met een kolomraster van acht bij acht meter, waarbij de kolommen, de liggers en de trek-druk schoren, vanwege de stabiliteit maar ook vanwege de tweede draagweg, allemaal in hout zijn uitgevoerd. En waar we de verbindingen zo hebben gemaakt dat ze nauwelijks zichtbaar zijn en heel snel montabel. Want je kent natuurlijk slisverbindingen met deuvels. Maar als je nou in het productieproces, de slisplaten al meeneemt in je gelamineerde hout en je zorgt dat je uiteindelijk met één twee of drie en vierentwintig nog maar koppelingen hoeft te maken. Dan heb je dus eigenlijk een snel montabel maar ook een demontabel skelet. En wat is er dan flexibel aan het skelet? Nou in die balken zijn gaten voorbereid voor het doorvoeren van leidingen en ladderbanen. Ladderbanen voor elektrotechniek. In de kanaalplaten zijn sparingen opgenomen. En in de kolommen zijn bussen met draad opgenomen. Zodat ze elk jaar met een nieuwe indeling scheidingswanden aan de houten kolommen kunnen zetten, zonder schroefgaten, beschadigingen te maken omdat je natuurlijk je C en je U-profielen van metal stud, of noem het maar op, die kan je met boutjes met volgringen gewoon op die voorbedachte posities monteren. Ja ik weet niet of het bijdraagt in je onderzoek, of je ermee bekend was?</p>                                                                                                                                                                                                                                                                                           |
| I  | Niet precies met deze oplossing, nee. Maar dit is wel een richting van flexibiliteit, absoluut.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| P3 | <p>Ik weet ook niet of je alleen opzoek bent naar vloeren? Of dat je ook naar constructies van opslagruimtes op zoek bent? Wij maken veel distributiecentra. Nou dat is veel vierkante meters, dus de kracht van de grote getallen. Dus weinig kilo's staal per vierkante meter. Met een hele grote vrijheid, dus weinig kolommen. En ook weer de ruimte om sprinkler- en allerlei installatietechniek, verwarming, verlichting en voeding, voeding elektra, voeding lucht, aan te brengen. Ja, is dat dan flexibel? Ja het is in ieder geval demontabel en je ziet terugkomende rasters omdat je met smalle en brede stellingpaden te maken hebt en dan heb je zo'n beetje alle variabelen gehad. Toch wordt elk gebouw uniek. Omdat het kantoor een beetje bijzonder moet zijn, omdat je webshops hebt met een dikke portemonnee en met een kleine portemonnee en omdat je locatie soms veelzeggend is. We hebben net acht boodschappen-thuisbezorg-hubs uitgerold voor [grote Nederlandse supermarkt] en dat zouden acht dezelfde hubs worden. Dus we hebben een prijsstelling afgesproken voor de eerste, het ontwikkelen van een concept. En daarna het herhalen van een tweede tot en met een oneindig. Nou de eerste van 100% honorarium, de volgende, ik zeg maar wat, 35%. We zijn er goed mee gevaren maar we hebben toch vijf verschillende variëteit gemaakt door de kavelindeling. Want we hebben toch laaddocks aan de voorzijde, laaddocks aan de achterzijde, laaddocks aan de lange zijde. Is het dan flexibel? Ja want de hoofdstaalconstructie hadden we iedere keer hetzelfde gemaakt, alleen we planten er frames tussen voor de overhead deuren naar de dock levelers, dat zegt je wel wat? Dus de fundering van</p> |

|    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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|    | <p>universeel en we hadden een hal van 26 meter 27 meter breed en die kon in principe over een van de beide zijanten worden gespiegeld. Dus we hadden aan drie gevels stabiliteit en de vierde zijde die had kolommen om de achttien meter met een vakwerkligger waar in principe rekening gehouden was voor het tweede dak van 27 meter. Zodat je dus de meters te allen tijde kon dubbelen op elke locatie. Nou dat kan nog steeds. Dus dan ben je eigenlijk flexibel en demontabel, remontabel eigenlijk. Dat woord heb je waarschijnlijk ook opgeschreven. En, ja goed, dan ben je natuurlijk met die CO2 print van het staal ben je heel erg goed bezig. Als je gaat naar woningbouw in CLT, ik weet niet of je daar al wat verder mee bent?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Ik heb een aantal voorbeelden ervan gezien.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| P3 | <p>Nou in Nederland zijn ze allemaal nog op zoektocht. In Duitsland, Oostenrijk, Canada, Noorwegen hebben ze alle informatie al en als je <a href="http://www.dataholz.eu/">www.dataholz.eu/</a> bezoek, dan heb je eigenlijk alles wat je nodig hebt om het in Nederland uit te kunnen rollen. Alleen om aan al je geluidseisen te kunnen voldoen, maak je eerste een houten wand als drager en daar schroef je massa op, metal stud of gipsplaat, afhankelijk of je een dubbele of een enkele bouwmuur maakt. En in het hout sla je zogenaamd CO2 op, dus je zou kunnen zeggen ik haal dat hout uit die bouwmuur, ik maak toch al metal stud, en ik zet alleen om de hoekpunten van mijn CLT-vloeren zet ik ondersteuning, waardoor ik naar een universele constructieopzet ga, waardoor ik mijn bouwmuren met mijn afbouw fase kan meenemen en waardoor ik in mijn bouwmuren meer stabiliteit kan realiseren dan alleen met mijn lichte houten wanden. Want normaal, als ze de hoogte in gaan met CLT, maken ze hybride een betonkern. En die is dan negen maanden planning en het hout is drie maanden planning. Maar stel dat je zegt van nee maar dat hout van die wanden kan ik gebruiken voor andere vloeren, dan sla je wel minder CO2 op, maar goed je kapt ook minder bossen om en die paar gram staal die je dan inbrengt die maken eigenlijk dat je je systeem dan later ook weer makkelijker uit elkaar kan halen. Kan je dan je installatie flexibeler kwijt en later aanpassen? Ja dat is eigenlijk onafhankelijk daarvan, want dat doe je in je ballast laag. Want je maakt, als het dan gaat over woningbouw, een houten drager, een grindlaag als ballast, een verende laag in minerale wol en dan eindig je met een cementdekvloer, wat je leefvlak is als laatste massa laag. In die eerste ballast laag en in die cementdekvloer kun je je installatie aanpassen. Want er is natuurlijk niets op tegen om een keer een sleuf ergens in te zagen en je installatie aan te passen. Dus dan ben je semi-flexibel. Of je geeft meer geld uit en je gaat met een Fermacell Estrich Floor achtige beplating werken in plaats van met die natte vloer dan heb je eigenlijk ook een heel flexibel systeem. Ik weet nog steeds niet of dat is wat je zoekt, hè. Want voor ons is dat dagelijkse kost en voor jou is het misschien iets wat je geleerd hebt, maar wat nog een beetje body moet krijgen. Dus dat het voor jou wel interessant is om het uit te diepen.</p> |
| I  | Ik denk wel dat je gelijk hebt in het tweede. Voor mij is het vooral, ik zit nog heel erg in de theorie fase eigenlijk. Dus het is op dit moment nog theorie en nog niet echt praktijk. En dit soort opmerkingen of deze voorbeelden die je geeft wat meer beeld vanuit de praktijk. Dat helpt wel een beeld vormen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| P3 | Volgens mij was je opzoek naar vloeren vooral, hè?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| I  | Ik ben opzoek naar vloeren vooral, inderdaad. Dat is mijn kader als het ware.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| P3 | Dus, en de uitdaging zit hem een beetje in, meer flexibiliteit leidt waarschijnlijk tot standaard een dikker vloerpakket.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| I  | Ja dat is zeker een uitdaging.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| P3 | <p>En een dikker vloerpakket bij bouwbesluiten over verdieping hoogte, leidt tot meer vierkante meters gevel. Dus het mes snijdt in die zin niet aan twee kanten, maar de kosten groeien aan twee kanten. Want je vloer is duurder en je gaat meer vierkante meter gevel investeren. En je gaat natuurlijk ook nog de hoogte in, dus je stabiliteit wordt complexer. Maar dat gaat natuurlijk niet zo hard. We gaan steeds meer inbreiden, daar is natuurlijk juist de uitdaging andersom. Kan ik met de toegelaten bouwhoogte één laag extra realiseren of niet. Wat heel nauw in verbinding staat met de haalbaarheid van je plan. Een voetprint van drie keer vier of keer drie, nou dat betekent wel of geen project hebben. Ik denk dat je dat wel moet uitschrijven. Dat je dat signaleert.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Ik ben me er bewust van dat de hoogte een item is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| P3 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

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|  | I   | Ja. En dat dat iets is wat van belang is. Ik heb wel ook begrepen dat, bijvoorbeeld, ze dat in Denemarken wel voor lief nemen, dat het iets hoger is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|  | P3  | Maar moet je Denemarken niet opsplitsen in Denemarken en in Copenhagen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|  | I   | Dat zou heel goed kunnen. Ik heb er vooral van horen zeggen, hoor, dus ik...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|  | P3  | Ah oké. Nou ik ben een beetje in Denemarken opgegroeid. Niet dat ik erin opgegroeid ben maar [persoonlijke details]. En daardoor vallen je dingen misschien op. Denemarken heeft 5 miljoen inwoners, is drie keer zo groot als Nederland en van die 5 miljoen inwoners, volgens mij wonen er 3 miljoen in en om Copenhagen. Dus is een andere dichtheid, is een hele andere casus, en dan heb je nog, nou ik zeg maar wat, 5 grote steden en dan heb je een hele tijd niets. Maar goed, ik vind het wel goed om dat te onderschrijven, want ik zie dat in Zweden in de verschillende filmpjes ook wel. Ik weet niet of je YouTube al uitgekamd hebt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|  | I   | Ik heb eigenlijk nog niet zoveel naar filmpjes gekeken voor mijn onderzoek, nee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|  | P3  | Oké, nou ja goed. Wij hebben dat systeem om de houten dragers met CLT te vervangen door stalen dragers. Daar zijn we geïnspireerd geraakt door Brock Commons. Dat is een pand in Vancouver. Alleen Brock Commons maakten ze nog een betonnen kern. Met het nadeel van het tijdspad en het nog steeds heel veel, hoe noem je dat ook alweer, delfstoffen, cement erin pompen. Maar daar hebben wij uiteindelijk aan verbonden van hé als je nou in de scheiding tussen je woning en je verkeersruimte, de gang, en tussen de verschillende vertrekken een aantal kruisen opneem, in die ankerloze spouw die je toch maakt, en je gaat dat slim detailleren. Dan kun je opeens je volledige trappenhuis kern prefabriceren en met trap en al erbij hijsen, in plaats van dat je die aan het kisten bent en trappen erin borduren en, maar goed. Dat is dan een zijsprong, maar daar heb ik wel geleerd dat op internet of op YouTube heel veel best gedetailleerde films te vinden zijn over voor nu vooruitstrevende bouwsystemen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|  | I   | Dat is een hele goeie, daar heb ik nog niet zo bij stil gestaan maar het is een goede om even te bekijken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|  | P3  | Ja, nou voor nu is mijn waterval een beetje op aan het drogen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|  | Q1b |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|  | I   | Nou ik zal even kijken want ik heb nog wel meer vragen opgeschreven. Ik heb nog de vraag: op welke manier neem je zelf flexibiliteit mee in je ontwerpproces? Is dat iets waar je bewust mee bezig bent?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|  | P3  | Ja als het gaat over bouwen voor ondernemers, voor bedrijven, bedrijfsruimten, dan gaat het altijd over restwaarde. Je kan zeggen, ik heb een hal nodig van 5 meter maar als je hem dan 6 of 7 mag en kan maken, kan elke heftruck onder de spanten door rijden. De verkoopbaarheid wordt dan beter. Ja ik heb maar een vloer nodig van duizend kilo per vierkante meter, ja maar als ik kijk naar de stapelbare hoogte, kan je het straks voor veel meer geld kwijt en aan veel meer mensen als je vijftientig honderd kilo aanhoudt of je houdt vijftig honderd kilo aan. Nou een architect tekent al snel ergens kolommen in. En wij zeggen altijd, je hebt constructeurs, adviseurs en je hebt rekenaars. Je kan zeggen die kolom die hoeft er niet persé in want met dat profiel ga je in één keer overspannen en dan heb je twee drie kilo per vierkante meter meer aan ijzer nodig alleen je hebt niet die ene kolom, die je ook nog kapot kan rijden, waar een poer en een paal onder moet, je kan manoeuvreren met dingen. Nou goed, dus dan heb je het al over flexibiliteit. En als je gaat naar kantorenbouw. Nou kanaalplaat is toch een beetje leidend. Vaak kies je voor liggersystemen met bijna vlakke plafonds zodat je weinig plenum ruimte verliest. Kanaalplaten met kantoorbelastingen, ja vijftien meter is niks meer, hè. Dus het kan allemaal. Dan moet je wel voor een vloer vijftig centimeter reserveren. Maar dat betekent wel dat je een prachtige flexibele ruimte hebt die je kan opdelen en splitsen, maar ook als open tuin kunt gebruiken dus in die zin ben je dan ook flexibel bezig. Appartementenbouw, heb ik ook wel eens gezegd, nou ik zie een raster waarbij je een stramien overslaat. En waarbij je dan de woning scheidende wand om en om in kalkzandsteen of beton uitvoert en daarnaast in een ankerloze metal stud, zodat je appartementen kan samenvoegen of zodat je het helemaal weg kan halen zodat het een dubbele grote wordt. Dat hoeft niet altijd kostenverhogend te zijn. Flexibel met installaties, ja dat is toch altijd lastig want de installateur begint pas na te denken als hij opdracht heeft. Hij wordt eerst zes keer door de wringer gehaald en maakt tien praatvoorstellen en dan hebben wij die constructie allang bij de betonfabrikant en de staalbouwer liggen, of bij de houtbouw, hè. We doen ook veel in hout. Dus in welke zin |



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|     |    | hou je dan rekening met je flexibiliteit, nou je brengt op ontwerpend niveau, maar ook op detailniveau, wij doen veel voor gevelbouwers, wij doen veel voor staalbouwers, voor houtbouwers, breng je in wat je in je bagagemandje hebt verzameld. Ik doe dit nu 30 jaar, [contactpersoon] iets korter maar ook al een tijdje. Ja maar dan kun je toch best heel veel neerleggen, maar je moet natuurlijk oppassen dat je niet alleen maar op die constructie focust. Want als je het te mooi maakt en om die reden word je teruggefloten, zit je zelf dubbel werk te doen. En daar willen ze niet altijd dubbel voor betalen. Dus je moet een beetje een balans vinden, hè. Ja. Maar flexibiliteit is nooit gratis.                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Nee. Er komt altijd een meerprijs bij kijken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | P3 | Ik denk het wel, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | I  | Dan is het aan degene die het betaalt om te kijken of dat het waard is, I guess.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P3 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Q1c | I  | Nou mijn volgende vraag is: wat zijn de huidige ontwikkelingen die je ziet op het gebied van flexibiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P3 | Ja ik denk dat in alles wat we tot op heden besproken hebben, dat je dat er wel uit kan filteren. Dus ik denk dat het te ver gaat om daar nu een soort resumé voor te maken. Die kan je er denk ik zelf wel uit distilleren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Ik denk het wel, als ik hem terug ga luisteren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P3 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Maar er is geen andere die je daar nog in zou benoemen? Het was wel vrij uitgebreid al.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P3 | Ik vind het lastig. Ik moet eerlijk zeggen dat ik ook niet een routine heb in het bijhouden van vakbladen of social media. Soms dan lees ik me helemaal suf en een andere keer laat ik het gewoon drie maanden ophopen. En dat heeft te maken met een balans tussen [privézaken].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Dat is prima hoor.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P3 | Ik denk dat wat [contactpersoon] en wij goed doen, dat we open met elkaar kennis en capaciteit delen. Dat zou onze hele branche moeten doen. En onze branche bestaat uit allemaal, gechargeerd hoor, mensen die hetzelfde vak uitoefenen maar die allemaal denken dat ze het beter weten dan de anderen en dat de opdrachtgever gek is dat hij het bij Pietje neerlegt. Dus de informatie die naar buiten komt via vakbladen is volgens mij een beetje een soort, nou ja, net wat aandacht vragen maar de maritus voor jezelf houden.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I  | Ja precies, kan ik me iets bij voorstellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P3 | En, nou ja, en goed, en de bouwcultuur is ter voeten uit, we doen het altijd al zo en zo, waarom zouden we het anders doen? Binnen de kaders die dan regelgeving heten, kun je best heel vrij ontwerpen. Ik denk dat wij als bureau heel veel lef in tonen en daar staan we ook om bekend. Maar dat heel veel bureaus juist kiezen voor allerlei standaardoplossingen en dat dat ook de remmende factor is. Dan kun je putten uit details die je al in andere projecten hebt toegepast, dat is lekker veilig want je hebt er gevoel bij wat eruit moet komen. Je vindt weinig weerstand, en dus ook leegloop van je uren, bij overheden die je werk controleren, je krijgt weinig vragen van onderaannemers die verder moeten engineren met jouw stukken, je krijgt dus ook weinig correspondentie van ja wij denken dat dit niet verstandig is. Hè, dus, maar dat is denk ik wel het gros van onze vakbroeders. Ja waar wil je bij horen, hè, waar voel je je prettig, waar vind je een uitdaging, of ga je alleen maar werken omdat je je boodschappen en je hypotheek moet betalen. |
| Q1d | I  | Ja, dat begrijp ik. Nou dan ga ik door naar de volgende vraag. En deze hebben we ook al even aangehaald, een beetje. Maar in mijn onderzoek definieer ik flexibiliteit dus als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. En, hier hebben we het al een beetje over gehad, maar ik wil de vraag bij jou neer leggen. Wat zou voor jou een ingrijpende ingreep zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P3 | Ja, toen jij je vraag nog eens herhaalde moest ik denken aan de NEN8700, zegt je dat iets?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | NEN8700? Nee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |



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| <b>P3</b> | Oké. Hij bestaat al een tijdje en hij zit gewoon in je KennisID, je Briswarenhuis, zul je ook wel gebruiken voor je regels. Maar heel veel collega's kennen hem niet of passen hem niet toe. Hij doet twee dingen. Hij stuurt de convergentie tussen oudere en nieuwere constructievoorschriften, of hoe noem je dat, rekenmethodes aan. Dus je hebt GTB 62, 72, 92 en daarna ben je naar de Eurocode gegaan. En bij de ene had je bij beton en staal een hogere veiligheid, later hebben we materiaalfactoren gekregen. En op basis van de probabilistiek, je weet wel, hebben we coëfficiënten. Alleen als ik een gebouw heb van toen en ik wil er nu iets meer, tussen haakjes, mee. En iets meer kan zijn, ik heb een kantoor met een paddenstoelvloer, weet je wat dat is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>I</b>  | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>P3</b> | Ja. Ik wil er appartementen in maken. Ik ga op strategische plekken mijn meterkasten plannen. De ene constructeur zegt hè daar moet een balk onder, hè daar moet een koolstoflamelle bij, daar kan geen gat zitten want je hebt een probleem met pons, noem maar op. Ik kan er geen twee lagen meer bij op zetten want de fundering heeft te weinig draagvermogen, ik krijg een tweede-orde probleem, die kern gaat zoveel harder door deinzen dat die in één keer uit de bocht schiet. Nou dat betekent dat je op zoek bent naar welke ruimte zit erin als ik daar als vakman rondloop en visueel gezien heb ik de indruk dat er goed gebouwd is en er is goed gerekend. Dus hij buigt niet extreem door, ik zie geen scheuren, ik zie geen andere vreemde schades. En die NEN8700 die zegt eigenlijk dat je risicoprofiel lager is als je aan die voorwaarden voldoet en dat je het mag aanwenden als de kosten om het op nieuwbouwniveau te herbouwen onevenredig zijn. Dus eigenlijk staat daar, als ik bedenk hoe ik het volgens de nieuwbouwvoorschriften doe en mijn opdrachtgever laat kosten bepalen en hij zegt ja maar dat heb ik er niet voor over en het is significant minder als ik het dan als verbouwen aanmerk, en dat betekent bijvoorbeeld CC2 dat je van 1,2 naar 1,15 en van 1,5 naar 1,3 gaat, alleen voor wind ga je van 1,5 naar 1,3. En dan zeg je nou dat is toch allemaal niet veel? Ja, het is wel veel. Omdat een gebouw uit 1962 of uit 1972, even ervan uitgaande dat de betonconstructie zo slank is dat de doorbuigingen niet uit de bocht schieten, maar ze deden 1,7 over permanent en veranderlijk. We hebben nu een materiaalfactor van 1,15, dus de convergentie is ongeveer 1,7 gedeeld door 1,15. Dat betekent dat je 1,49 keer permanent plus 1,49 keer veranderlijk rekende in die tijd, waar je nu dus op verbouw niveau met 1,15 en 1,3 mag rekenen. Dat betekent dat je op permanente belasting 30% van je eigen gewicht, dus hoe zwaarder een vloer, hoe meer ruimte er ontstaat. En op veranderlijke belasting ga je van 1,49 naar 1,3, dus daar ontstaat ook nog wat ruimte. Nou stel je hebt een oude wapeningstekening, je gaat die vloeren met de tabellen van de GTB narekenen of je stopt hem slim in een FEM-model, je print daar de meetkast sparingen in, en je kunt, omdat die vloerbelasting omlaaggaat van kantoor naar wonen, hè, ik heb het over een lokaal iets, ik controleer de vloer. Dus je kan tegen je opdrachtgever zeggen nou je mag gewoon die meterkast sparingen eruit halen mits, nou ja met de ronding van de zaag niet voorbij de hoeken gezaagd wordt. Ik weet niet of je kent dat dat belangrijk is. Anders zaag je toch weer een paar staven extra kapot. Mits, maar. Dan maak je iemand gelukkig! Want dat betekent dat er geen balken onder hoeven, dat er geen versterking onder hoeven. En vervolgens in die voorschriften rekenden ze de bovenste laag 100%, dan 90%, 80, 70, 60, 50, 40, 40, 40, 40, 40, 40. Dus dat betekent dat je naar je fundering kan kijken, hè, wat je vroeger fundamentele combinatie is geweest. En als je dan kijkt wat het met die verbouw eisen van de NEN8700 is, dan heb je na het draagvermogen van je funderingsvoeten en na de pons van je kolommen op je poeren, heb je een stukje ruimte. Als je dan gaat optoppen met een slimme constructie, ik heb laatst op een kantoor van 23 meter het verzoek gehad, kunnen er twee lagen op? En toen ik had gezegd ja dat kan, toen werden het twee lagen met een sheddak. Dus eigenlijk tweeëneenhalve laag. En toen heb ik gezegd, als we daar ongeschoren portalen van maken, dan grijpt de windkracht van alles wat erbij komt nog steeds aan op 21 meter. Dat betekent in je hefboomsarm iets anders dan dat je, wat was het, 33 in het kwadraat vergelijkt met 24 in het kwadraat. En in je tweede-orde scheelt het ook wat. Nou uiteindelijk is dat succesvol opgetopd. En, hoe zeg je dat, het heeft al een paar keer heel hard gewaaid, nou je voelt je er best veilig! En degene die destijds het pand bouwde is een prefab bouwer met een eigen betonfabriek, die links en rechts nog wel eens de neiging heeft om, nou zij noemen het praktisch, maar te overwapenen. Dus in de fundering waar kantelingen naar palen moesten worden |

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|                                       |    | <p>verdeeld, in de betonwanden waar in knopen momenten moesten worden doorgegeven, daar zat wel wat ruimte. Nou ja, dat allemaal zo verzamelend, kun je hele leuke dingen doen. En nou heb ik laatst een sprekend voorbeeld gehad. Een architect benaderde mij, en dat was een plan waar ik drie jaar geleden nee tegen had gezegd omdat ik geen tijd had en iemand anders had het uitgewerkt. En die had op zijn tekening gezet dat op de knopen uit 1950 tussen de kolommen en de liggers, schotten moesten worden ingelast. Dat doen we tegenwoordig en vroeger keken ze daar niet zo naar. En als je het aanstort en het wordt rondom ingebetonneerd, kun je dan wel lokaal knik van je lijf boven je kolom krijgen? Nou misschien niet. Misschien kun je wel hybride denken, dat een deel van je stuitkracht uit je bovenste kolom via betondruk en een deel via, nou ja, rondingsstralen en lijf naar je onderliggende kolom wordt doorgegeven. En anderszins zit er ruimte in die NEN8700, hè. Nou ten eerste had die constructeur nog nooit van de NEN8700 gehoord. Dus die rekende met veel te hoge belastingen. Hij had zich ook niet verdiept in hoe de regels er in 1952 eruitzagen. En de creativiteit om te zeggen nou stel dat ergens een holle ruimte zit en mijn lijf staat zeg 2 millimeter vrij en hij zou iets rond gaan staan, hè, hoeveel is dan die knikkracht die hij tegen het omliggende beton afzet? En hoe verhoudt zich dat? Ja peanuts natuurlijk. Nou ja, lang verhaal kort. De aannemer had uitgerekend dat het driehonderdduizend euro moest kosten om al die knopen vrij te hakken en platen in te gaan lassen. En dat was na de aanbesteding, dus die opdrachtgever was daar ziek van. Dus die architect, die benaderde mij, kun jij er eens naar kijken en zie je kansen? Nou, heeft dit met flexibiliteit te maken? Nou het is eigenlijk een zijstraatje op die NEN8700, die wel kansen en flexibiliteit biedt. Maar goed, nou doe er maar iets mee. Ik weet het niet. Ik dwaal helemaal af.</p> |
|                                       | I  | Nee dat is prima, maar ik zou toch graag terug willen komen op de vraag. Wat is in dit opzicht dan, wanneer is het een ingrijpende ingreep?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                       | P3 | O ja, want zo kwamen we erop. <b>Ingrijpende ingreep. Ik denk dat als de kosten om het aan te passen buitenproportioneel zijn. Als je nieuwbouw voor 15 euro per vierkante meter iets kan realiseren en verbouw voor vijftientighonderd alleen hij schiet door naar vijfentientighonderd. Ja dan is dat wel buitenproportioneel denk ik.</b> En een constructie, wat kost die gemiddeld?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                       | I  | Durf ik niet te zeggen, hoor.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | P3 | Nee dat dacht ik. Nee ik eigenlijk ook niet. Nee, maar, je geeft het allemaal uit aan je constructie. Dus als je het spiegelt op alleen je draagstructuur en je voorzieningen brandwerendheid op bezwijken en je calamiteit die je moet borgen. Dan gaat het wel over substantieel veel geld als je opeens duizend euro per vierkante meter meer moet uitgeven, want je hele constructie kost geen duizend euro. Je hebt wel meegekregen, dat verhaal in Eindhoven, daar zullen jullie ook wel op ingegaan zijn. Ik heb in projecten aan tafel gezeten en daar zat al heel snel een vloerenleverancier aan tafel en die kwam ook met de bollenvloer. Nou dat is flexibiliteit, hè, grotere kolommenafstanden of minder funderingsgewicht. En mijn vraag was wat kost die vloer. Nou die kostte toen 130 euro franco werk. En we bouwden zes lagen, dus ik zeg oké we hebben veertig euro meer, keer zes lagen is 240 euro meer. Wat bespaar ik dan in de fundering? Want die fundering kost maar honderd euro per vierkante meter. Dus dan kun je niet uitleggen dat je 240 euro meer gaat uitgeven om minder fundering te gaan maken. Ja nou hoe ga je dan uitleggen wat veel en wat weinig is, hè. Het is heel subjectief. Dat zul je toch per project, denk ik, met gezond verstand moeten bekijken. Ik weet ook niet of dit de algemene antwoorden zijn waar je op zit te wachten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | I  | Nee hoor! Iedereen geeft andere antwoorden en dat is juist wat ik zo interessant vind aan deze interviews, de verschillende perspectieven. Dat bedoelde ik ook op het begin. Ik ben niet echt op zoek naar een bepaalde soort antwoorden. Ik probeer een beeld te krijgen, zal ik maar zeggen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Q2a                                   | I  | Ik heb als volgende vraag een hele basale vraag. Wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                       | P3 | Ja nou ja. <b>Een vlak. Waarop je je begeeft binnen of buiten een gebouw.</b> Ik denk dat dat het wel is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | I  | Dus het gaat er vooral om dat het vlak is en dat je erop kan zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | P3 | Nou ja, <b>het helpt je om er makkelijker op te zijn. Als het op hoogte is moet je ander vliegen of hangen. En als het op niveau is, dan kan het minder nat zijn of minder zanderig. Dus gelijkmatiger. Dus het helpt je het gebruiksgemak te vergroten.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

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|                                              | I  | Ja oké, mooi antwoord.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Topic 3: Opportunities and challenges</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | I  | Ik zie dat de tijd bijna om is. Ik heb nog twee vragen, heb je daar nog tijd voor?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                              | P3 | Jawel jawel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Q3a                                          | I  | Oké. Als allereerste, het zijn ook twee vragen die compleet aan elkaar gerelateerd zijn. De eerste vraag is welke kansen zie je voor flexibiliteit? Met betrekking tot vloeren en jouw vakgebied.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                              | P3 | Nou weet je, als ik daar nu een antwoord op kon geven. Dan had ik waarschijnlijk allang het ei van Columbus uitgevonden. De moeilijkheid is volgens mij dat je er nooit achter komt wat het echt kost en wat het echt mag kosten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q3b                                          | I  | Dat haakt meer in met mijn laatste vraag: welke uitdagingen en obstakels zie je?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                              | P3 | [Persoonlijke relatie] is ooit de geestelijke vader achter de kalksteenelementen in Nederland geweest. Zij gingen de markt op met heel veel kennis vanuit de aannemerskant, de adviseurskant en de architectenkant. Eerst zei iedereen wat moet ik met die gekke rotblokken. En toen ze er een lijmbakje bij hadden en een klein kraantje en toen ze tijden geklokt hadden op kraamkamers, hè, bouwplaatsen die eraan mee wilden werken, was het al vrij snel 60% van de bouwmarkt. Alleen intern heette het het witte goud. En dat was omdat ze heel goed hadden gekeken wat kosten vergelijkbare systemen. Wat zijn aannemers, ontwikkelaars kwijt aan een vierkante meter afgewerkte wand. En daar zijn ze een beetje omheen gaan spoken. Maar dat was natuurlijk helemaal niet wat dat spul kostte. Dus daar werd gewoon de eerste tientallen jaren werd gruwelijk veel aan verdiend. En dat is natuurlijk niet een op zichzelf staand verhaal. Dat is gewoon ondernemen. Maar dat is denk ik ook de remmende kracht achter innovatie dat we allemaal natuurlijk iets willen overhouden voor later en voor een beter leven dan iemand die gewoon van half negen tot half vijf zijn dingetje gaat doen, maar niet betrokken is en niet gepassioneerd en niet. En daartussen zit nog heel veel wat ook niet afkeurenswaardig is. Het is gewoon heel moeilijk om te vernieuwen, denk ik. |
|                                              | I  | Dat is de grootste uitdaging? Dat het moeilijk is om te vernieuwen en dat er...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | P3 | Ja omdat het snel natuurlijk op financiële weerstand. En weet je, wij zitten in heel veel trajecten waar mensen duurzaam woningbouw willen plegen. Nou dan zou je dus in CLT kunnen bouwen. En dat willen we dan allemaal graag. En dan zeggen ze aan de voorkant, zou je dan binnen dezelfde opdracht eerste het VO willen helpen uitdenken in CLT en dan haken we een kostendeskundige aan. Nou dat is eigenlijk niet de goede partij en niet alle aannemers zijn geschikt om dat uit te rekenen. Maar als het dan tegenvalt gaan we naar traditionele oplossingen. Het is altijd van het VO naar het DO, doe toch maar kalkzandsteen want ik wil wel zoveel rendement halen. En het rendement oogmerk en het gebrek aan kennis en doorzettingsvermogen, is gewoon, denk ik, je hele obstakel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                              | I  | Ja dat kan ik me voorstellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

Table B.7: Transcription interview P4

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| Interviewee                              |    | P4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Client and market manager at a large Dutch construction firm |
| Date and time                            |    | March 25 <sup>th</sup> 2021                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 8:00                                                         |
| <b>Topic 1: Flexibility of buildings</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                              |
| Q1a                                      | I  | Mijn allereerste vraag is: Kun je me vertellen over de ontwikkelingen in de bouw die van interesse zijn voor jou of je vakgebied? En dat is niet persé flexibiliteit gerelateerd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                              |
|                                          | P4 | Ontwikkelingen in de bouw, die voor mij interessant zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                              |
|                                          | I  | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                              |
|                                          | P4 | Oef. Dan ga ik een beetje hoger over. Ik hou me best wel bezig met hoe kunnen we wat we doen klantgericht maken. Heeft ook met plattegronden te maken. Ik ben bijvoorbeeld best wel bij betrokken bij [prefab woonoplossing project], ken je wellicht wel of niet. En daar hebben we dan bijvoorbeeld een levensloopbestendige woning, die is nieuw. En wat mij dan bezighoudt is, oké we maken een plattegrond en die bedenken we heel erg super technisch. En wat maakt dit nou echt een levensloopbestendige woning? Is dat dan de, dan is dat vaak toch ons eigen perspectief en is het eerst, wordt het vanuit de techniek bedacht en daarna gooien we er een soort sausje overheen en |                                                              |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
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|     |    | <p>zetten we hem in de markt als levensloopbestendige woning. Want hij is zo breed of er is een slaapkamer beneden en dat soort dingen hebben we dan in de basis over gedacht. En dan heb ik het met mijn collega erover, welke dingen zouden wij tenminste moeten doen die klanten belangrijk vinden. We hebben ook echt een klantenonderzoek gedaan en ik baal er dan van dat dat niet gelijk aan de voorkant is meegenomen, maar aan de achterkant wordt gekeken van oké hoe kunnen wij die dingen als opties toevoegen. Terwijl er enkele dingen zijn, zoals bijvoorbeeld een brede deurpost, die je niet makkelijk meer, daar moet je echt grote bouwkundige aanpassingen op doen, op het moment dat je die woning echt levensloopbestendig wil maken. Dus hoe kunnen we nou in ieder geval die dingen adresseren en meenemen in de basisplattegrond van de woning. Dus het houdt me heel erg bezig hoe we onze producten nu écht klantgericht maken. En tegelijkertijd moeten onze producten ook concurrerend blijven. En dat vind ik echt een lastig spanningsveld. Maar ik geloof ook wel dat als je een heel goed verhaal hebt en die compleetheid kan uitleggen, en als je dat overal op die manier standaard toevoegt, dat dat best wel prima kan werken alsnog. Als jij kan laten zien dat je een completer woning hebt en een externe partij wel die appels met appels gaat vergelijken. Dus dat is een belangrijk ding dat mij bezighoudt. Betaalbaarheid houdt mij ook heel erg bezig. Hoe houden we nou al onze producten betaalbaar en wat betekent dat dan, hoe diep kun je daarin gaan. Nou ja, we kennen natuurlijk ons [woonconcept], maar al onze producten moeten natuurlijk betaalbaar zijn. En waar heb je het dan over? Heb je het alleen over het moment dat je dat product neer zet, of, dat gaat natuurlijk ook over de materialen die je gebruikt en dergelijke. En het spanningsveld daarmee ook met het belang van de omgeving die daarbij zit. Hoe maak je een gezonde omgeving voor mensen, waarin je dus goed kan oud worden. Of als je dan in een appartementengebouw woont dat je dan wel ook een goeie buitenruimte eromheen hebt. En dat spanningsveld is best wel lastig. Dat houdt me ook wel bezig. Ja, sociale cohesie, dat stuk vind ik ook echt een belangrijk ding.</p> |
|     | I  | Dat zijn de thema's die je bezighouden?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P4 | Dat zijn de thema's die zo even bij me oppoppen als je het zegt. Waarschijnlijk als ik daar langer over na had gedacht dan kom ik nog wel tot wat andere dingen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Nou mocht je nog iets bedenken waarvan je denkt dat had ik echt nog willen zeggen, dan mag dat.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P4 | Ja, ik vraag me ook af, zeg maar, het is ook niet allemaal helemaal relevant. Ik ben ook wel veel bezig met biodiversiteit wat meer. Ik woon zelf in een nieuwbouwwoning, waar we verplicht de struiken in de tuin moesten laten staan, of de beukenhaag eigenlijk. En wij zijn van de veertig vijftig woningen de enige woning nog, met onze ene burens, de andere kant wilde dat niet, die nu nog een groene afscheiding hebben, zeg maar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | O dat is bijzonder!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P4 | Ja vind ik bijzonder en echt heel interessant. Want het is namelijk echt super slecht om alles helemaal dicht te gooien. En hou kan je nou zorgen als bedrijf dat je kopers meer meeneemt in de waarde van groen en ook dat het goed is om een gedeelte van je tuin groen te houden of water doorlatend te houden. En dat het ook niet allemaal heel veel werk hoeft te zijn. Als je de juiste dingen kiest, kan het ook zo zijn dat het allemaal best wel meevalt. En voor je persoonlijke geluk en gezondheid is het ook nog heel erg goed. En dat houdt mij persoonlijk ook wel heel erg bezig. En ik zie het dus ook iedere dag en ik irriteer me er ook heel erg aan. Maar ik denk ook hoe kunnen we dat nou beter doen. Want we hebben daar best wel invloed op, als bouwbedrijf ook, uiteindelijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | Ja dat is wel interessant inderdaad.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P4 | Maar goed dat is helemaal off topic.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I  | Maar dat maakt het niet minder interessant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Q1b | I  | Met mijn tweede vraag gaan we iets verder naar flexibiliteit. Kun je mij vertellen hoe er vanuit jouw vakgebied naar flexibele of aanpasbare gebouwen gekeken wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P4 | We hebben het heel veel over flexibele aanpasbare gebouwen. We hebben ook, hoe heet dat project ook alweer? In [middelgrote stad in Nederland]. Naja het is in ieder geval een verzorgingsplek voor mensen met een verstandelijke handicap. En die woningen, ik zit tegelijkertijd keihard te denken hoe dat heet, nee ik ga het niet bedenken. Maar die woningen, zeg maar, die zijn weer van één woning naar twee woningen te maken. Dus die zijn ook gewoon te maken naar plekken waar particulieren uiteindelijk weer hun intrek in zouden kunnen nemen. Maar in ieder geval, flexibiliteit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|     |    | <p>wordt naar gekeken. Dat is de meest voorkomende, eigenlijk, die ik een beetje hoor. [Naam van project] heet het. Dat is iets. Vanuit [jongere organisatie van bedrijf], dat is wel leuk. Wij hebben allemaal groepjes die gedurende het jaar nadenken van wat klopt er niet, wat zouden we beter kunnen doen, kwamen er ook allemaal ideeën hierover naar voren. En daar ging het meer over het aanpassen van, waarom zou je niet één losse module als huis kunnen kopen en dat je daar weer modules op zet en als je dat niet meer nodig hebt er weer modules af gaan en die weer ergens ander terecht komen. Ik merk wel dat de organisatie haakt niet heel erg op dat soort dingen aan. Daar wordt niet heel erg in geloofd. En je ziet ook bij [woonconcept] die losmaakbaarheid, die is natuurlijk heel erg interessant, vooral als dat die in [grote Nederlandse stad] is neergezet. Maar ik merk wel ook dat dat wordt leuk gevonden, interessant gevonden, maar ik hoor heel veel in de organisatie van ja leuk dat we dat doen, maar ik geloof niet dat we ooit zo'n woning daadwerkelijk echt gaan verplaatsen, zeg maar. Dus flexibiliteit van gebouwen of woningen, dat wordt wel veel benoemd, maar ik denk ook nog wel dat het een beetje nog een trend woord is en dat we nog niet echt volledig weten waar we het over hebben. Of in ieder geval dat er meer mogelijk zou moeten kunnen zijn.</p> |
|     | I  | En waar ligt dat aan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P4 | Geloof. Of dat we dat echt zo allemaal gaan doen, denk ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Dat je geen glazen bol hebt, dat je niet weet of het echt zo gaat lopen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P4 | Ja. We hebben wel, in de basis hebben we gezegd, ik heb het hier liggen, ik heb meerdere ondernemingsplannen hier liggen. Ja in de basis hebben we gezegd dat we altijd kijken voor toekomstbestendig gebruik, waar mogelijk adaptief, aanpasbaarheid van functie van een gebouw eigenlijk. Daar hebben we een heel onderzoek mee gedaan met. Ik ga je dat sturen, is dat goed?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Is goed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P4 | Ik schrijf dat even op. Want het is wel één van onze kerndingen, dat wij hebben gezegd van wij gaan altijd gaan we dat hieraan toetsen. Is hetgeen wat wij neerzetten, is dat flexibel? Is dat aanpasbaar? Maar dieper dan dat, concreet, hebben we het niet gemaakt. Dus wat bedoelen we daar dan precies mee? En dat is wat ik bedoel, van in hoeverre is dat geland?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Geen indicatoren van o dan is het aanpasbaar?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P4 | Nee precies, precies dat.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | I  | Interessant, grappig. Dus het is iets wat wel echt actief aanwezig is, maar nog niet uitvoer heeft, zal ik maar zeggen, of geen handvatten heeft.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P4 | Nee, ik voel hem niet op die manier. Maar dat is ook echt vanuit mijn rol gezegd. Ik kan me heel goed voorstellen dat sommige mensen, als ze met een bepaald project bezig zijn, ze dat heel anders voelen. Maar ik voel van dat hebben we met elkaar gezegd en ik hoor ook wel eens andere geluiden                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Q1c | I  | Nou in mijn onderzoek definieer ik flexibiliteit als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. Wat zou vanuit jouw perspectief een ingrijpende ingreep zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P4 | Een ingrijpende ingreep.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | Ja. In het Engels is dat een 'intrusive intervention'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P4 | Oké. Nou eigenlijk, het project waar ik het net over had die [projectnaam], is niet een ingrijpend ingreep. Er zijn zelfs badkamers zo bedacht dat, naja, dat valt allemaal best wel mee, zeg maar. Ik denk op het moment dat je aan gevels moet gaan komen, dat dat ingrijpend is. En ik vind het ook afhankelijk van voor wie het is. Dus als het voor de bewoner is, wat ik net aangaf, dan vind ik de deurpost aanpassen, eigenlijk iedere bouwkundige ingreep vind ik dan al een ingrijpende ingreep. En als het over meer business-to-business gaat, ja dan mag er wel wat meer aangepast worden en meestal heb je dan ook al te maken met andere wanden waardoor je wat voor elkaar kan krijgen. Dus dan gaat het meer om de buitengevel, dan vind ik het ook ingrijpend worden. En ook ingrijpend als mensen er nog in zitten. Als het te maken heeft met iets leegstaands, wat je moet veranderen, of weet ik veel wat, dan wordt het alweer een heel ander verhaal. Maar op het moment dat dat de situatie is, dan is het totaal niet flexibel voorgedacht, zeg maar. Ik weet niet of dat meer de vraag aan de voorkant was, maar ja.                                                                                                                                                                                                                                                                      |



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|                                          | I  | Je kunt dan inderdaad, als ik het zo hoor, op twee niveaus zien. Je hebt dingen die een bewoner zelf, die tijdens een woonfase, zal ik maar zeggen, aangepast kunnen worden. En als je echt naar een andere functie gaat, of wat dan ook, dan zitten er waarschijnlijk geen mensen meer in. Ik kan me voorstellen dat je daar onderscheid in kan maken voor wat een ingrijpende ingreep is.                                                                                                                                                                                                                                                                                                                                                                         |
|                                          | P4 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Topic 2: Flexibility of floors</b>    |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Q2a                                      | I  | Oké, nou dan gaan we iets dieper in op de vloeren. Even kijken. Hoe kan flexibiliteit van vloeren een toegevoegde waarde voor jou of je vakgebied zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                          | P4 | Voor mij en mijn vakgebied. Dan wordt hij al heel snel heel plat. Want ik geloof wel heel snel van van de voorkant, als je dat verhaal vertelt als het gaat over levensduur. Dat vind ik super relevant en ik denk dat het super relevant is voor de wereld van onze klanten. Ik kan me ook echt wel voorstellen dat ze daarop aanslaan. Ik was me daar zelf namelijk niet zo van bewust, dat dat zo was. Dus dat vooral. Het is voor mij is het relevant ook weer richting onze klanten.                                                                                                                                                                                                                                                                           |
|                                          | I  | En denk je als klanten dat weten, zal ik maar zeggen, dat hun vloeren gewoon ingestort zijn, dat de installaties ingestort zijn in hun vloer, dat zij daar dan voordeel in zien, of is dat een beetje een ver-van-hun-bed-show?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                          | P4 | Ligt eraan over welke klant je het hebt. Voor kopers is het een ver-van-hun-bed-show, dat is heel moeilijk allemaal te begrijpen. Ook al heb je daar natuurlijk ook mensen die dat wat meer aanvoelen en die superkritisch zijn. Maar voor andere partijen, ik denk dat dat heel erg relevant is. Die houden zich, beleggers, coöperaties, die houden zich natuurlijk super veel bezig met de levensduur van hun vastgoed en wij als bedrijf zijn ook heel veel bezig met de [onverstaanbaar], van hoe blijf je nou relevant naar de toekomst toe. We hebben natuurlijk een grote voetprint, ja daarvoor is het super relevant om hiernaar te kijken. Dus enerzijds relevant voor de klanten, maar je moet ook kritisch naar dat soort dingen, als bedrijf, kijken. |
| <b>Topic 3: Incentives and obstacles</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Q3a                                      | I  | Ja, oké. Nou dan gaan we er rap doorheen. Mijn laatste onderwerp is dus kansen en uitdagingen. En daarin is mijn eerste vraag: welke prikkels denk jij dat er nodig zijn om flexibiliteit mee te nemen in de plannen of het beleid dat gevoerd wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                          | P4 | Welke prikkels?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                          | I  | Ja, zeg maar het wordt nu nog niet, tussen aanhalingstekens, voldoende gedaan. Hoe kan dat gemotiveerd worden?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                          | P4 | Financiële prikkels werken altijd heel erg goed. Financiële prikkels, die gaan dan meer over de toekomst. Dat eigenlijk die Total Cost of Ownership. Ik geloof ook heel erg in, wat ik net aangaf, in de duurzaamheidsambitie. Iedereen wil beter doen voor de wereld en heeft er tegenwoordig ook best wel wat meer voor over. Dat is nog steeds wel een spanningsveld, maar veel minder erg dan een paar jaar geleden. Dat zijn de twee die ik zo kan bedenken.                                                                                                                                                                                                                                                                                                   |
|                                          | I  | Klinkt ook heel logisch.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Q3b                                      | I  | Dan, welke kansen zie jij voor flexibele bouw?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                          | P4 | Welke kansen zie ik voor flexibele bouw? Kun je die ietsje specifieker maken? Of kun je een voorbeeld geven?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                          | I  | Even kijken. Nou eigenlijk is het een vraag met twee delen. In eerste instantie wil ik vragen van welke kansen zie je en in het tweede deel wil ik vragen welke uitdagingen en obstakels zie je? De kansen is, ja hoe leg je dat uit, nou stel we zouden flexibele bouw gaan doen, welke voordelen denk je dat we daaruit gaan halen?                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                          | P4 | Je gaat van mij weer platte dingen krijgen hoor.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                          | I  | Helemaal mooi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                          | P4 | Ik denk dat. We gaan dingen slimmer doen. Ik zit heel erg te denken wat is de tegenhanger, trouwens. Van, we doen nu natuurlijk ook in zekere mate flexibele bouw, maar ook weer niet. Dus dit is flexibeler. Je gaat meer toekomstbestendige producten neerzetten eigenlijk, uiteindelijk. Dat is een groot voordeel. Maar ja dat is echt, dat is zo'n inkopper. Ik weet niet, ik zit ook even te denken of er qua logistieke bewegingen ook nog echt verschillen in zitten. Dat zou kunnen en dan zouden we er ook voordelen uit kunnen halen, als we het daardoor slimmer kunnen inrichten. Nee, ik weet het verder niet.                                                                                                                                        |
| Q3c                                      | I  | Ook geen uitdagingen of obstakels? De andere kant van het muntje, zal ik maar zeggen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |



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|                              | <b>P4</b> | Nou in het algemeen, uitdagingen en obstakels, denk ik dat die er altijd wel zijn. Want we hebben alsnog, want we maken wel enorme stappen als hele sector, maar er wordt nog wel heel sceptisch gekeken als het gaat om allerlei van dit soort ontwikkelingen. Ook op de bouw, zeg maar, zelf, van moet dit, hoe moet dit? Gaat het wel goed zo? Niemand zit erop te wachten. Dat soort dingen. Ik kan me altijd voorstellen dat je daarmee te maken zal hebben, enige vorm van weerstand. Maar dat is in iedere, altijd als je iets verandert.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                              | <b>I</b>  | Waar komt die weerstand vandaan denk je?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                              | <b>P4</b> | Onwetendheid. En angst. Weerstand komt uit angst.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                              | <b>I</b>  | Oké, wijsheden.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                              | <b>P4</b> | Ja, dat is volgens mij echt zo, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                              | <b>I</b>  | Dus vooral weerstand, omdat het nieuw is en nog onbekend is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                              | <b>P4</b> | Ja en misschien ook wel, ik heb geen idee of het daar betrekking op heeft, maar dat is dus ook dat angst stuk, van wat betekent dit voor mijn werk? Als dit soort dingen verder door worden gevoerd, ben ik dan nog wel nodig? Dat soort dingen. Ik vraag me wel af, of waar je mee bezig bent, of dat verschil wel zo drastisch groot is. Eigenlijk zie ik dat niet persé gelijk. Maar ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Discussion afterwards</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                              | <b>I</b>  | Nou dat zijn mijn vragen. Ik weet niet of je verder nog wat mist of iets toe wil voegen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                              | <b>P4</b> | Nee, wat ik al zei, enerzijds staat het, ook weer niet en ook weer wel, best wel ver van mij vandaan. Ik heb gewoon niet heel veel technische kennis. Dus nee, ja. Maar wat heb jij nog aan klanttevredenheid of eindgebruikersperspectief waarvan jij denk van daar ben ik nog nieuwgierig naar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                              | <b>I</b>  | Ik wil dus ook wat meer naar de eindgebruiker kijken, maar ik moet wel zeggen dat ik dat vrij lastig vind. Ik heb ook een interview staan met een woningcorporatie bijvoorbeeld, op die manier probeer ik een beetje de eindgebruiker meer te nemen. Maar ik denk ook, wat je zegt, dat het heel moeilijk is om het hier met de eindgebruiker over te hebben. Want je moet net die eindgebruiker hebben die hier mee bezig is. Zoals je zegt, dat iemand die een koophuis koopt er meestal niet over nadenkt, behalve als die net die persoon is die dat wel doet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                              | <b>P4</b> | Ja en daar ben je dan waarschijnlijk weer niet echt naar op zoek, hè. Je bent opzoek naar de gewone bewoner of de gewone kantoorgebruiker of wie dan ook.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                              | <b>I</b>  | Ja precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                              | <b>P4</b> | Maar wat voor effect heeft het ook op hun?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                              | <b>I</b>  | Nou, uiteindelijk is een bouwelement dat flexibel is waarschijnlijk in eerste instantie duurder. Dus dat zou de prijs iets omhooghalen. Wat een voordeel zou kunnen zijn is, nou wat ik begrepen heb is dat mensen ook graag voor jaren 30 woningen gaan omdat die ook makkelijker aanpasbaar zijn. Die vloeren kun je opengooien, daar kun je van alles in aanpassen en dan kun je het weer dicht gooien. En dat kan niet zo goed met nieuwbouwvloeren. Dan moet je ze echt, dan moet je die ingrijpende ingreep doen, zal ik maar zeggen. En dat terwijl, tien twintig jaar geleden was iedereen telefoonkabels aan het aanleggen omdat je net internet had en nu gaat het allemaal draadloos. En waarschijnlijk over tien jaar heb je weer allemaal andere eisen over wat er aan installatie in je huis en in je vloer moet zitten. Dus het voordeel voor een eindgebruiker zou kunnen zijn dat je dat relatief makkelijk kan aanpassen. Dat je kunt denken van goh we hebben nu gewoon hele andere eisen, tegenwoordig willen we een weet ik veel wat systeem en ik heb mijn huis dan wel tien jaar geleden gekocht, maar ik weet dat dat kan, zonder dat ik mijn hele vloer eruit hoef te halen. Dat zou een voordeel kunnen zijn. |
|                              | <b>P4</b> | Ik denk dat daar een groot ding in zit hoor. Eigenlijk lijkt het nu een beetje op wat ik net zei over die biodiversiteit. Mensen hebben best wel onwetendheid, ook, over alles rondom hun huis. En op het moment dat je ze op de juiste manier mee weet te nemen, op de juiste momenten, dan denk ik dat mensen echt wel bereid zijn om ervoor te betalen. En zeker bij nieuwbouw geldt het natuurlijk ook nog eens, je betaalt het natuurlijk, je voelt het minder hard, omdat het in je hypotheek zit. En ik vind het ook heel grappig wat je zegt over jaren 30 woningen, want ik heb er nooit over nagedacht dat mensen voor een jaren 30 woning kiezen om hem aan te passen. En ik geloof wel inderdaad, het is makkelijker om je woning aan te passen, maar het is natuurlijk ook wel een stuk minder comfortabel in de basis.                                                                                                                                                                                                                                                                                                                                                                                                    |

|  |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | I  | Ja klopt, het is natuurlijk ook de uitstraling van een jaren 30 woning. Maar als je een nieuwbouwwoning koopt denk je in eerste instantie ook niet aan het aanpassen. Want hij is net nieuw. Dus alles is al goed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|  | P4 | Nee daar ben je nog helemaal niet mee bezig. Dat klopt. Nee en ik hoor ook altijd dat mensen dan kiezen voor de sfeer en je hoort ook heel veel van nieuwbouwwoningen van ja daar zit geen sfeer in. Maar dat is inderdaad zo, je kan daar alles mee doen. En hier, of in ieder geval als ik kijk naar mijn huis [nieuwbouw], ik heb alleen de zolder aangepast. Want dat was een grote lege ruimte, daar hebben we wanden in laten zetten en een dakkapel op geplaatst, zoals half Nederland doet als ze een nieuwbouwwoning kopen. Ja ik denk wel dat je dan dat stuk. Dus je gaat echt van al die doelgroepen uit, je gaat uit van kopers, huurders,                                                                                                        |
|  | I  | Ja ik ben het aan het verkennen. Uiteindelijk is dat natuurlijk niet helemaal mijn studie.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|  | P4 | Nee, ik probeer een beetje te denken hoe ik je verder kan helpen van hoe je die dus kan implementeren. Of dat je die ergens zijdelings kan raken,                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|  | I  | Naja wat ik zeg, het is niet helemaal mijn studie, dus zou misschien iemand anders zich daar verder in kunnen verdiepen. Maar ik was eigenlijk vooral bezig met, ik wilde graag kijken naar het perspectief van alle eindgebruikers om te kijken van goh als er iets uit komt wat echt van belang is dan kan ik dat direct meenemen in de rest van mijn ontwerp en onderzoek. Dus in die zin ging ik uit van alle eindgebruikers. Al denk ik wel, wat ik ook uit andere interviews een beetje distilleer is, dat je voor zoiets nieuws, een nieuwe ontwikkeling, misschien toch eerst bij de beleggers of coöperaties moet komen. Want die kunnen in eerste instantie de voordelen al wat beter overzien. En dat lijkt me een beter begin, zal ik maar zeggen. |
|  | P4 | Ja dat snap ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|  | I  | En als dat duidelijk is, dat je dan wat meer naar de particuliere kant kan kijken. Nou dat is wat ik er, een beetje, nu uit haal. Want die hebben meer dat overzicht van wat nou voor- en nadelen zijn en waar je op let, als investeerder.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|  | P4 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|  | I  | Maar ja. Ik weet niet of jij nog in, hoe zou je dat zeggen, in wensen die voor een particulier in dat opzicht misschien anders kunnen zijn dan voor een coöperatie? Zouden zij op andere dingen letten?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|  | P4 | Ze letten sowieso op andere dingen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|  | I  | Ja dat geloof ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|  | P4 | Nee, dat er. Wat ik je wel kan sturen, heb je misschien ook helemaal niets aan. Ik heb een onderzoek over de toekomst van wonen, waarin we 450 klanten, in de breedte, landelijk, hebben gevraagd over wat zij wel en niet relevant vinden. Geen idee of je er wat aan hebt. Het is onderverdeeld in beleggers, ontwikkelaars, gemeenten en coöperaties. En daar zie je best wel grote verschillen in, tussen die klanten. Van particulieren hebben we dat nog niet, of we zijn wel continue aan het kijken, daar komen andere soort dingen naar voren. Maar misschien heb je hier wel wat aan.                                                                                                                                                                |
|  | I  | Klinkt interessant, in ieder geval om te kijken wat de tendens is. Ja, heb je nog andere suggesties of ideeën hoe ik particulieren of kopers mee zou kunnen nemen? Of denk je dat dat...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|  | P4 | Nee, ik ga wel mee in jouw gedachte. Dat je ergens moet beginnen en dat je beter kunt beginnen bij de business-to-business klant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|  | I  | Ja, nee oké. Goed om even over nagedacht te hebben.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|  | P4 | Het is wel interessant hoor, want misschien is het wel hartstikke haalbaar. Iedereen is zuinig op zijn portemonnee, op de lange termijn ook. Dus als je het goed kan vertellen, denk ik dat er wel wat te halen valt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|  | I  | Dan moet je echt op een stukje bewustzijn inzetten. Dat men weet waar het over gaat.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|  | P4 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

Table B.8: Transcription interview P5

|                                   |                             |                                                              |
|-----------------------------------|-----------------------------|--------------------------------------------------------------|
| Interviewee                       | P5                          | Structural engineer at a medium-large Dutch engineering firm |
| Date and time                     | March 30 <sup>th</sup> 2021 | 15:30                                                        |
| Topic 1: Flexibility of buildings |                             |                                                              |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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| Q1a | I  | De eerste vraag is: kun je mij vertellen over de huidige staat van flexibiliteit in jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P5 | Ja dan bedoel je echt flexibiliteit in constructies, hè?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | I  | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P5 | Ja op zich, het is natuurlijk een vrij breed begrip, hè. Wat ik in ieder geval kan doen is even laten zien hoe wij daar binnen [bedrijf waarvoor P5 werkt] mee om gaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | Is goed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P5 | Wat ik in ieder geval even kan laten zien, is misschien wel leuk, een beetje context, is hoe wij bij [bedrijf waar P5 voor werkt] over duurzaamheid denken. Even kijken hoor, dan ga ik even mijn scherm delen, dat is misschien het makkelijkst. Je kan nu mijn scherm zien hé? [Webpagina over duurzaamheid van bedrijf waar P5 voor werkt]. Dus heel globaal, binnen [bedrijf waar P5 voor werkt] zijn we natuurlijk ook steeds meer bezig met duurzaamheid omdat je, ja, je zegt het zelf ook, we merken dat het iets is wat steeds vaker gevraagd wordt en, ja, we moeten er iets mee. En het is op zich ook, het is eigenlijk hartstikke leuk om erover na te denken. Binnen [bedrijf waarvoor P5 werkt] ben ik dan ook een van de mensen die een beetje de kar trekt daarvan. En wat we binnen [bedrijf waarvoor P5 werkt] nu als visie hebben, dat is eigenlijk dat er verschillende mogelijkheden zijn om duurzaam te ontwerpen. Daar hebben we deze diagram voor ontwikkeld [te zien op gedeeld beeldscherm]. Dus eigenlijk is het idee dat, ja, er is niet echt één manier om duurzaam te ontwerpen, maar eigenlijk kan je verschillende kanten op. Eigenlijk onderscheiden wij vier hoofdrichtingen. De eerste is herbestemming, dus eigenlijk het behouden van wat je al hebt in plaats van nieuwe gebouwen neer te zetten. Wat eigenlijk per definitie al duurzaam is want dan gebruik je in ieder geval geen nieuwe materialen. Je hebt ontwerp voor een lange gebouwlevensduur, dat is denk ik een beetje waar jij nu in die hoek zit. Dus dat gaat vooral om het ontwerpen van gebouwen zodat ze heel lang mee gaan. Dus ontwerp voor flexibel gebruik. Bijvoorbeeld dat je zegt nou we willen een kolommenstructuur in plaats van een wandenstructuur. Dat is iets wat we binnen projecten ook vaak tegenkomen, wat ook vaak wordt gevraagd. Nou ja goed, dat is dus een van de mogelijkheden. Verder zie je ontwerp voor meerdere levenscycli, dat is dat je gaat kijken, niet op gebouw niveau maar echt op element niveau dat je een gebouw ontwerpt om later te kunnen demonteren bijvoorbeeld. Wat vooral interessant is als je weet dat een gebouw in de toekomst gedemonteerd gaat worden, dat je nadenkt van hoe kunnen we dat nou uit elkaar halen. De andere kant is eigenlijk de vraag van moet je iets demonteerbaar maken als je weet dat het vijftig jaar op dezelfde plek blijft staan. Want we hebben ook wel eens projecten dat er wordt gezegd ja we willen heel graag demontabele kanaalplaat vloeren bijvoorbeeld, dat is nu helemaal, dat gebeurt nu vrij, dat is nu vaak in het nieuws. Dat wordt dan gevraagd terwijl er helemaal geen perspectief is dat het later ook echt gedemonteerd gaat worden en dan zeggen wij meestal van je kunt gewoon beter gewoon een robuust gebouw neerzetten wat flexibel is in de indeling en wat gewoon constructief goed in elkaar zit met het idee dat het ook voor vijftig of honderd jaar blijft staan, in plaats van dat je bij voorbaat al allemaal demonteerbare elementen erin gaat stoppen terwijl je weet dat dat helemaal niet nodig is. Dus dat is een beetje de afweging die daar speelt. En als vierde richting hebben we dan nog duurzaam materiaalgebruik. En dan kijk je echt op element niveau. Dus echt naar van hoe kunnen we nou het materiaalgebruik sowieso minimaliseren. Als het goed is gebeurd dat sowieso in constructies, want het is gewoon goedkoper. Maar dan kun je bijvoorbeeld ook denken naar het kijken voor het minimaliseren van je milieu impact of je MPG-score, ik weet niet of je daar bekend mee bent? |
|     | I  | Ja daar ben ik bekend mee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P5 | Na ja dus dat doen we ook nu steeds vaker. Bijvoorbeeld dat we verschillende vloeren naast elkaar leggen en we kijken van welke scoort nou het beste op die MPG. Na ja bijvoorbeeld ook het gebruik van hout valt daaronder. Dat is natuurlijk nu een beetje een hot topic, iedereen wil bouwen met hout. Dus dat is ook een beetje een richting die daaronder valt. Nou dus eigenlijk hebben we die vier richtingen en het idee is een beetje dat we per project eigenlijk kijken, wanneer die ambitie er is, als de opdrachtgever zegt van ik wil een duurzaam gebouw, dan kijken wij op basis van die diagram eigenlijk welke strategie het meest van toepassing is. En het is dus een beetje afhankelijk van het project welke richting we op gaan en of we dan ook echt gaan sturen op die flexibiliteit bijvoorbeeld.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

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| Q1b | I  | En in welke gevallen zou je gaan sturen op flexibiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P5 | Ja dat is denk ik vooral de gevallen waarvan je weet dat het gebouw er echt lang blijft staan, of in ieder geval als we uit gaan op flexibiliteit op gebouw niveau, dat je op gebouwniveau zegt van ik wil veel flexibiliteit in indeling. Ja ik zit even te denken, ik heb bijvoorbeeld op dit moment een project voor een school in [grote Nederlandse stad]. Nou daar is bijvoorbeeld één van de uitgangspunten dat we vooral echt bijna alleen maar kolommenstructuur toepassen, bijna geen vaste wanden met het doel dat het hele gebouw flexibel indeelbaar is. Dat we nu een bepaalde indeling kunnen kiezen, maar dat het over tien jaar weer anders ingedeeld kan worden. De manier waarop we dat doen is dat we dus nu voor een kolommenstructuur kiezen. Verder gaan we ook uit van een veranderlijke belasting van 5 kN/m <sup>2</sup> . Zodat je ook vrij bent in wat je waar neer zet. Daar kiezen we voor omdat daar wordt ook echt specifiek naar gevraagd. En een schoolgebouw is wel typisch zo'n gebouw wat nu nieuw wordt gebouwd en waarvan het idee is dat het wel de komende vijftig jaar echt wel daar blijft staan. Dus dan kun je maar beter zorgen dat het, ja, dat je zoveel mogelijk flexibiliteit inbouwt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | Ja. Oké. Dan kan ik wel direct doorgaan naar de volgende vraag, die haakt hier goed op in. Als je zelf aan het ontwerpen bent, hoe neem je dan flexibiliteit mee in je ontwerpproces? Je geeft natuurlijk al het voorbeeld van de kolommen. Zijn er nog andere items?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P5 | Ja even denken. Ja qua ontwerpaspecten, wat neem je dan mee? Ja ik denk vooral die kolommenstructuur is belangrijk. En toch vooral die veranderlijke belasting. Dat je daar gewoon genoeg ruimte in hebt. Het is natuurlijk ook altijd een balans vinden tussen aan de ene kant die heel ruim nemen, dat je zegt nou we berekenen alles op die 5 kN/m <sup>2</sup> , zodat we er alles mee kunnen. Maar aan de andere kant wil je natuurlijk ook niet over dimensioneren. Want, ja, straks. Ja de keerzijde is dat je uit gaat van een veel te hoge belasting, die eigenlijk nooit op treedt waardoor je veel te veel materiaal in je constructie zit. Dus dat is wel altijd een beetje een afweging die je in je achterhoofd moet houden. Maar goed in dit geval hebben we wel gezegd we gaan overall uit van die 5kN/m <sup>2</sup> , want dat was ook toevallig een eis vanuit de opdrachtgever. Ja dus denk ik die twee dingen zijn belangrijk. Wat verder natuurlijk ook speelt is de integratie van installaties in je constructie, of eigenlijk, het voorkomen daarvan. Wat je ziet bijvoorbeeld is dat je, tegenwoordig als je massief betonnen vloeren hebt, dan worden installaties best vaak ingestort. En dan kun je je afvragen hoe duurzaam dat natuurlijk is, want stel dat over twintig jaar die installaties verouderd zijn, dan kan je ze niet zomaar uit die betonnen vloer gaan halen. Dus dat is ook wel iets waar we vaak over nadenken. Dat bijvoorbeeld, in die school dan, hebben we gezegd we gaan uit van kanaalplaten met geïntegreerde liggers. Dus in plaats van dat die liggers onder de vloer uitsteken zitten ze in hetzelfde vlak waardoor je heel vrij bent in je leidingverloop. Dus dat hou je dan sowieso los van elkaar. |
|     | I  | Je bent vrij in je leidingverloop. Zit dat dan nog wel in de hoogte van je kanaalvloer of dat niet?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P5 | Nee dat niet. Nee wat je eigenlijk krijgt. Ben je een beetje bekend met het principe van kanaalplaatvloeren met geïntegreerde liggers?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | Een beetje.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P5 | Het zegt wel iets?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Ja precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P5 | Even kijken of ik snel een voorbeeldje tevoorschijn kan toveren. Even kijken dan ga ik heel even mijn scherm weer delen. [Detailtekeningen]. Even de goeie zoeken. Hier bijvoorbeeld zie je, dit is een detail waar dit is de kolom. Dan de stalen ligger, die haaks erop doorgesneden en aan beide kanten ligt er dan zo'n kanaalplaatvloer ligt op de onderflens van die stalen ligger. Dit is dan een THQ ligger of een hoek ligger, wordt dat genoemd. Door zo'n oplossing in plaats van te zeggen, ik heb zo'n vloer en ik doe daaronder mijn stalen ligger. Door het op deze manier op te lossen zorg je er eigenlijk voor dat die, je totale vloerdikte is natuurlijk vrij beperkt en hier onderdoor kun je gewoon vrij leidingen laten lopen,                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Gebruik je dan een verlaagd plafond daarvoor, of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P5 | Ja. Ja in dit geval worden ze allemaal weggewerkt onder een verlaagd plafond geloof ik. Dus dat is op zich nog wel handig. Want stel je hebt over twintig jaar andere leidingen nodig of je hebt een andere indeling waardoor dat moet wijzigen. Dan kan dat heel                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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|     |    | <p>makkelijk dus onder die constructie. Daar heb je genoeg ruimte om dat allemaal op te lossen, in plaats van dat, stel je hebt hier een stalen ligger waar je echt een gat in moet maken, precies op de plek waar een leiding doorheen gaat, dan kan je daar natuurlijk veel minder in schuiven in de toekomst. Dus dat zijn eigenlijk, dat is ook wel weer een typisch uitgangspunt dat we hebben om ook die flexibiliteit te waarborgen. Ik zit even te denken of er nog meer aspecten zijn. Ja het is natuurlijk ook altijd project specifiek een beetje wat de speerpunten zijn. Maar ik denk dat in dit geval, dus ja vooral de kolomstructuur, de veranderlijke belasting, en het gescheiden houden van je installaties en je constructie, dat is vooral wel belangrijk.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q1c | I  | Oké, nou dan ga ik lekker door naar mijn derde vraag. Wat zijn de huidige ontwikkelingen op het gebied van flexibiliteit binnen jouw vakgebied? Zie je dingen die nu een beetje opkomen als het ware?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P5 | Ja dat is een goeie vraag. Even denken, bedoel je dan nog steeds flexibiliteit op gebouwniveau, dat je flexibel bent in je indeling, of ?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | I  | Mag ook op element niveau, dat maakt niet zoveel uit.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P5 | Ik zit even te denken, wat je nu ziet is er wordt ook vaak gevraagd naar echt demontabele constructies. Dat is natuurlijk flexibiliteit op echt een element niveau. In plaats van dat je zegt ik behouw mijn hele gebouw en ik maak dat gewoon robuust, merk je steeds vaker dat je wordt gevraagd om echt flexibele constructies als in dat er delen uitgehaald moeten kunnen worden of juist aangebouwd kunnen worden. Dan heb je ook weer te maken met van die demontabele vloeren bijvoorbeeld. De laatste tijd is er best wel wat ontwikkeling op het gebied van demontabele kanaalplaatvloeren. Die vloer die ik net ook liet zien, is een vloer die vaak toegepast wordt bij kantoorgebouwen bijvoorbeeld. Daarvan wordt nu vaak gevraagd van kunnen we die niet zo detailleren dat die later ook weer gedemonteerd kan worden. Dus echt ook weer als een soort legosysteem uit elkaar gehaald kan worden. Dat is iets waar nu ook best wel onderzoek naar gedaan wordt, ook bij verschillende bureaus. Kijk wij hebben er nu een onderzoekje naar gedaan en een bepaald detail ontwikkeld. Je ziet dat [middel klein ingenieursbureau] bijvoorbeeld, een ander ingenieursbureau, die heeft een paar jaar terug ook een project gedaan met van die demontabele kanaalplaatvloeren. Dat is iets waarvan je merkt dat daar wel veel vraag. Ja je merkt dat als het één keer gebruikt wordt, dan denkt iedereen o een demontabele kanaalplaatvloer, dat wil ik ook wel in mijn project. |
|     | I  | Dan is het hip.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P5 | Ja, dat merk je dan. Ja dat wordt dan door architecten, dan is het ja dat willen we ook. En dan komt ook die afweging weer van hebben we dat echt nodig of doen we het puur om het dan demontabel te kunnen noemen? Dus ik denk dat dat wel een belangrijke vraag is die je moet stellen. En ja verder op het gebied van flexibiliteit. Ja wat je ziet is dat er natuurlijk constant weer nieuwe vloersystemen worden ontwikkeld. Volgens mij zijn er nu ook bepaalde vloersystemen, ik kan even niet op die naam komen, vloersystemen die echt ontwikkeld worden, aan de ene kant voor de demontabeliteit, maar aan de andere kant ook dat ze flexibel ingezet kunnen worden voor de integratie van installaties bijvoorbeeld. Dus dat, ja dat speelt. Maar goed, voor het algemeen, het blijft natuurlijk ook zo, dat de bouw is in die zin vrij conservatief. Ik denk dat in die zin, dat de ontwikkelingen die er zijn, ja die gaan ook best wel langzaam. En men is over het algemeen toch wel huiverig om echt hele nieuwe vloersystemen te gaan gebruiken.                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Heb je een idee waardoor dat komt? Gewoon puur door de conservatieve sfeer of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P5 | Ja, ik denk dat de bouw, de bouw als geheel is vrij conservatief, in de zin dat we het graag doen zoals we het altijd al hebben gedaan. Als wij bijvoorbeeld met een aannemer spreken dan wordt er vaak gezegd ja kunnen we het niet zo doen, want zo doen we het altijd en dat vertrouwen we. Dus als er geen ervaring mee is, is men al gauw huiverig om het toe te gaan passen omdat het dan niet echt zeker is of het ook echt veilig is of dat het werkt. Dus in die zin is men best wel risicomijdend. En dat maakt gewoon dat er eigenlijk maar heel weinig, in de bouw in het algemeen zijn de winstmarges ook vrij laag, waardoor er over het algemeen ook weinig geld beschikbaar is voor echt research en development. Dus dat zorgt er ook voor dat we vaak, deels uit gemak deels uit efficiëntie, toch gaan voor de bestaande oplossing waarvan we al weten hoe het werkt. Daarin zijn constructeurs, ja ligt er natuurlijk een beetje aan wie je spreekt, maar over                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |



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|                                       |    | het algemeen zijn constructeurs ook wel van het doen zoals we het kennen en alles wat daarvan afwijkt dat is toch eng zeg maar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                       | I  | Ja precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Q1d                                   | I  | In mijn onderzoek definieer ik flexibiliteit dus als het vermogen om een object aan te passen, zodat het aangepast kan worden aan veranderende eisen of omstandigheden, zonder de noodzaak voor een ingrijpende ingreep. En dan is mijn vraag aan jou: wat zou voor jou een ingrijpende ingreep zijn?                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | P5 | Ja dan bedoel je met object?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | I  | Een bouwelement, zal ik maar zeggen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | P5 | En dan specifiek een vloer of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                       | I  | Ja bij mij gaat het dan specifiek over een vloer maar als je andere input hebt, vind ik het ook interessant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | P5 | Nee maar meer of je het echt over een bepaald element hebt of dat je meer naar het gebouw zelf kijkt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | I  | Het gaat wel echt over een element.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | P5 | Het is natuurlijk sowieso zo. Nou je kunt natuurlijk op gebouw niveau zeggen we gaan flexibel ontwerpen. En op gebouwniveau zou ik dan zeggen het is flexibel op het moment dat je eigenlijk niets aan de constructie hoeft aan te passen. Aan de andere kant zou je, als je de installaties helemaal los houdt, dat je gewoon de installaties kunt vervangen zonder iets aan de constructie te veranderen. Want ik denk dat zodra je iets in die constructie zelf moet gaan doen, dan is dat al vrij ingrijpend. En goed, als je meer op element niveau kijkt, dan ben je eigenlijk al een stap verder. Dan zeg je eigenlijk al van ik ga het demonteren. Ik denk dat het op dat moment toch al wel vrij ingrijpend is. |
|                                       | I  | Zo kun je het ook zien.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P5 | Jij kijkt specifiek naar hoe je vloeren flexibeler kan maken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                       | I  | Ik kan anders ook wel een voorbeeld geven. Ik heb al verschillende mensen van verschillende achtergronden gesproken. De één vindt het niet ingrijpend zolang het, zal ik maar zeggen, de functie van de vloer niet aantast. Dus zolang die vloer kan blijven doen wat het moet doen, dan is het verder niet ingrijpend. Dat betekent dat je er in kan zagen of whatever. Terwijl de ander inderdaad, naja eigenlijk, alles wat je niet zonder het aantasten van het materiaal kan veranderen, ingrijpend vindt. Dus als je schroeven losdraait, dat is dan niet ingrijpend. Maar als je, weet ik veel, iets wat vastgelijmd is los moet halen dan is wel ingrijpend. Daar zit een hele range tussen.                     |
|                                       | P5 | Ja het is natuurlijk ook iets wat ook subjectief is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | I  | Ja vandaar de vraag.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | P5 | Ja ik zou zeggen, vanuit mijn rol als constructeur, van zolang het gaat om bouwkundige dingen, zeg maar. Bijvoorbeeld de afwerking op de vloer veranderen of een ander plafond installeren. Dat dat, ja dat is natuurlijk wel werk, maar zodra je iets aan de constructie wil wijzigen. Dan kan je dus denken aan bijvoorbeeld een hele vloer eruit halen of een gat maken in de vloer waardoor je ook weer voorzieningen moet treffen. Of, ja, stel dat je zegt ik heb een vloer en daar wil ik eigenlijk een zwaardere belasting op doen maar dat kan niet. Dan heb je allemaal aanvullende maatregelen nodig. Dan wordt het al snel ingewikkeld en ingrijpend.                                                        |
|                                       | I  | Ja dat kan ik me voorstellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                       | P5 | Als dat een beetje je vraag beantwoord?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | I  | Ja dat denk ik wel. Dat is best wel goed gekaderd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                       | P5 | Mooi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Q2a                                   | I  | Nou dat was eigenlijk mijn eerste topic. Dan wil ik nu meer toespitsen op vloeren, al ging deze vraag natuurlijk ook al een beetje over vloeren. De eerste vraag is een hele algemene vraag: wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P5 | Ja dat is een goeie vraag. Ja in principe een vloer toch in basis een element wat verticale belasting kan dragen. Ja je zal er ook vast allemaal definities voor hebben wat dan een officiële vloer is maar...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                       | I  | Dus een vloer kan belasting dragen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | P5 | Ja dat denk ik ja. Dat vooral, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                       | I  | Prima! Klinkt ook als een constructief antwoord.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |



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| Q2b | I                                            | Nou we hebben het over mijn volgende vraag al wel een beetje gehad. Maar ik ga hem toch stellen om te kijken of er nog wat anders naar boven komt. Kun je me vertellen over de huidige staat van flexibiliteit in het ontwerpen van vloeren? We hebben het al gehad over het geheel loskoppelen van installaties...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P5                                           | Ja ik denk als je specifiek, want we hadden het net natuurlijk een beetje over het gebouwniveau ook, als je specifiek kijkt naar vloeren, is denk ik op het gebied van flexibiliteit... Ja, één ding is natuurlijk de keuze op welke belasting je hem berekent. Dus of je zegt ik wil er die 5 kN/m <sup>2</sup> op rekenen of minder. Dat bepaalt natuurlijk in hoeverre de vloer flexibel is in de zin van hoeveel belasting die kan dragen. En wat verder belangrijk is, dan kom je toch weer op het loshouden van de verschillende systemen, dus die installaties. Maar je hebt bijvoorbeeld ook van die systemen dat je vloerverwarming in de vloer stort bijvoorbeeld. Ik denk dat dat ook allemaal overwegingen zijn die de vloer ook meer of minder flexibel maken. Dus zolang je de constructie los kan houden. En de bouwkundige en installatietechnische er los boven of onder toevoegt, dat dat wel in grote mate de flexibiliteit bepaalt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Q2c | I                                            | Oké. Nou de volgende vraag: welke trends zie je in de ontwikkeling van constructief ontwerpen die invloed kunnen hebben op het ontwerp van vloersystemen. Dat hoeft niet persé flexibiliteit gerelateerd te zijn, maar gewoon trends die jij ziet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P5                                           | Ja dat is ook een goeie vraag. Ik moet zeggen dat ik ook niet zo lang al meedraai dat ik kan zeggen nou de afgelopen jaren gaat het echt die kant op. Ja over het algemeen, wat je wel ziet, en dan kijk je echt meer naar materialen, dat houten vloeren wel echt upcoming zijn, zeg maar. Ja in een vloer, een houten balklaag bijvoorbeeld, dat is helemaal niet een nieuw systeem. Maar je merkt wel dat daar, omdat ja men vraagt meer naar duurzame gebouwen, men vraagt meer naar biobased alternatieven. En daardoor merkt je wel dat er een trend gaande is dat er meer naar houten vloeren wordt gevraagd. En dat kan dus, ja wat ik al zei, die houten balklaag, dat is een systeem wat eigenlijk al heel lang bestaat. Maar juist ook nu, omdat je van die, je wil ook wel een langere overspanningen kunnen maken met je vloer. Ook vanuit flexibiliteit, dat je dus minder kolommen, wil je grotere overspanningen. En dat in combinatie met dat er houten vloeren worden gevraagd, dat zorgt er ook voor dat ook CLT vloeren steeds vaker worden toegepast. En je hebt zelfs soort van houten kanaalplaten. Dat zijn soort van houten doosjes zeg maar, dus met van die hoge balken en met aan beide kanten een houten plaat. Die systemen kunnen best wel lange overspanningen maken. Dus je merkt dat dat, over het algemeen, is dat wel een trend die je ziet. Daar moet ik wel bij zeggen dat dat vaak begint, dan beginnen ze een project met we gaan alles in hout doen. En dan laten wij natuurlijk zien wat de opties zijn. Maar dan loop je eigenlijk vrij snel tegen een aantal problemen aan. Waarvan de belangrijkste is natuurlijk de kosten. Want je kunt je voorstellen, zo'n houten vloer is natuurlijk wat duurder dan de standaard betonnen alternatieven. Ja dus op het moment dat zo'n houten vloer echt wordt toegepast, dat betekent wel dat daar ook echt budget voor moet zijn. En een ander ding dat daar speelt is het, is ook het gedrag, het trillingsgedrag. Want eigenlijk, ja die houten vloeren, die zijn veel lichter en daardoor zijn ze ook veel trillingsgevoeliger dan bijvoorbeeld een betonnen vloer, waarvan wordt gezegd nou dat is zo zwaar, dat komt sowieso wel goed. En daarnaast heb je ook allemaal, met akoestiek heb je ook weer aandachtspunten. Ja eigenlijk op heel veel vlakken. Die houten vloeren zijn heel innovatief en dat is ook allemaal mogelijk, maar op heel veel vlakken heeft het wel extra aandacht nodig, vergeleken met een betonvloer waarbij het sowieso goed gaat. Dus op het gebied van akoestiek, brand bijvoorbeeld. Er zijn best wel wat aandachtspunten nog. Maar als je het echt hebt over innovatieve vloersystemen, is het denk ik vooral die houten vloersystemen wat echt opkomend is. |
|     | I                                            | Hout is booming. Ja dat heb ik ook al wat meer gehoord inderdaad.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P5                                           | Dat verbaast me niets.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | <b>Topic 3: Opportunities and challenges</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Q3a | I                                            | Als laatste wil ik het hebben over de kansen en uitdagingen. Nou een tweeluik van vragen en we beginnen met: welke kansen zie je voor flexibiliteit met betrekking tot het ontwerpen of meenemen van vloeren in jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P5                                           | Ja welke kansen zie ik?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | I                                            | Op welke manieren kan het aantrekkelijk zijn voor jou of voor je klanten eventueel?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P5                                           | En dan bedoel je op het gebied van flexibiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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|     | I  | Ja, flexibiliteit van vloeren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P5 | Ja ik zou zeggen dat de kansen die, ja ik denk vooral die vloeren die kunnen voldoen aan de eisen die worden gesteld vanuit flexibiliteit. Dus dat je bijvoorbeeld installaties makkelijk los kan houden of dat je ze op de een of andere manier kan integreren. Dat is bijvoorbeeld bij die houten kanaalplaatvloeren het geval. Dan blijft er een soort van open ruimte over waar je die kanalen in kan stoppen. Ja en verder denk ik ook vooral vloersystemen die echt die lange overspanningen kunnen maken, zodat je zo min mogelijk kolommen hoeft toe te passen. Wat ook weer voordelig is voor je algehele flexibiliteit. En verder, dan kom je toch wel weer op die demontabele vloersystemen. Dat dat wel iets is wat steeds vaker ook gevraagd wordt. En dan merk je ook wel dat de voorkeur dan automatisch al uitgaat naar vloeren die demontabel ontworpen kunnen worden. Dus de traditionele betonvloer die valt dan eigenlijk heel snel af als je echt zou willen demontabel bouwen. En dan ga je ook echt richting die kanaalplaatvloeren maar ook houten vloeren. Dus dat is denk ik wel een belangrijke. Beantwoord dat een beetje je vraag?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Ja hoor, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q3b | I  | Nou dan de andere kant van deze tweeluik. Welke uitdagingen of obstakels zie je voor flexibiliteit met betrekking tot vloersystemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P5 | Nou ik denk dat je dan ook wel komt snel bij de algehele conservatieve instelling van de bouw en de constructeurs die het moeten berekenen natuurlijk. Want in potentie zijn er heel veel nieuwe systemen die je zou kunnen ontwikkelen. Dat zie je ook wel op het gebied van die houten vloeren bijvoorbeeld. Er zijn ontzettend veel goeie ideeën, maar men moet het wel willen gebruiken. Dus aannemers moeten ook durven zeggen van we gaan voor een innovatief vloersysteem in plaats van de standaardoplossing. Dat is de ene kant van het verhaal. En de andere kant is dat constructeurs er ook kennis van moeten hebben of dat die dat ook willen leren. Want ik merk ook op het gebied van hout, ja het aantal constructeurs dat echt goed is in houtconstructies berekenen, dat is gewoon heel beperkt. Daarin merk je ook dat wat constructeurs over het algemeen over hout weten versus wat ze over beton en staal weten, ja dat loopt best wel achter. Is gelukkig niet helemaal weg. Elk ingenieursbureau heeft denk ik wel wat specialisten op dat gebied. Maar je merkt toch wel dat als een constructeur een bepaald materiaal of bepaald systeem niet kent dat het toch heel snel is van nee laten we dat maar niet doen, dan maken we het alleen maar moeilijk en lastig. Dus dat is denk ik ook wel een effect dat je niet moet onderschatten. Wat ook heel erg afhankelijk is van de constructeur natuurlijk. Hier bij [bedrijf waarvoor P5 werkt] bijvoorbeeld, kan ik je ook zo een aantal constructeurs aanwijzen die vrij conservatief zijn, maar bijvoorbeeld wel heel veel weten van de traditionele systemen. En aan de andere kant zijn er constructeurs die het juist leuk vinden om met innovaties bezig te zijn. Maar goed dat is nog niet de standaard helaas. Nee dus ik denk dat vooral. Dat de bouw toch iets meer zich zou moeten richten op nieuwe systemen en zich daar ook op zou moeten richten, in plaats van eigenlijk altijd maar uit gaan van een standaard oplossing. |

Table B.9: Transcription interview P6

|                                          |                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Interviewee                              | P6                    | Consultant at a small Dutch building services and building physics consultancy firm                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Date and time                            | April 1 <sup>st</sup> | 15:00                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Topic 1: Flexibility of buildings</b> |                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q1a                                      | I                     | Kun je mij vertellen over de huidige staat van flexibiliteit binnen jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                          | P6                    | Ik acteer natuurlijk vanuit installaties, bouwfysica, brandveiligheid en akoestiek. En mij valt op dat, in het algemeen, van onze kant van het spectrum er weinig over nagedacht wordt. Het is super traditioneel denken. Ja dat is het eigenlijk. En wat wij doen met ons bureau, wij proberen te vertellen dat de drager en de inbouw 100% gescheiden moet zijn. En dat betekent dat in de betonconstructie geen installatietechnische leidingen mogen komen. Maar als je dat inbrengt in de markt, is dat ongelooflijk complex. Een supermooie referentie voor jou om te gaan kijken hoe het gemaakt wordt, dat heet de [wooncomplex] in [grote Nederlandse stad]. Dat wordt nu gebouwd en daar is de drager en de inbouw 100% gescheiden. Maar eer de partijen zover met elkaar rond waren en ons verhaal geloofden, dat heeft even geduurd. Maar de bouw is gestart. En het is ook |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|     |    | indrukwekkend om te zien hoe dat ook gaat. Het doel van ons was, omdat wij zien dat de arbeidskrachten in de bouw teruglopen, het vaak laagwaardig werk is wat in de uitvoering plaatsvindt, je hoeft niet echt intelligent te zijn om een leidinkje in de vloer te leggen, maar die arbeidskrachten zijn relatief duur. Dus laagwaardige arbeid is relatief duur en ze zijn minder beschikbaar. Dus het is niet slim om in de seriematige woningbouw, waar Van Wijnen ook mee te maken heeft, dat dat gewoon niet handig is om het zo te maken. Je kan beter naar op een andere plek de leidingdelen assembleren, of tenminste, samenstellen en op de bouwplaats assembleren in van tevoren afgesproken plekken hoe je dat op de vloer zou kunnen leggen. Dus het idee bij ons is, ons perspectief is 100% drager en inbouw scheiden van elkaar. Nou dan komt de volgende kant, dat is dan de prefab betonvloeren en wanden. Er moet toch een wandcontactdoosje ergens naartoe. Hoe doe je dat dan op een slimme manier? En ten tweede, hoe krijg je dat lichtpunt midden in die betonvloer. Hoe doe je dat op een slimme manier zodat dat voldoet aan brand en geluidseisen, dat de bovenburen elkaar allemaal niet horen. Nou dat is de uitdaging. Dus het is eigenlijk super simpel om te zeggen, maar ongelofelijk complex om op te lossen. En dat ene lichtpuntje waar ik het over heb, daar zijn we ongeveer tien vergaderingen over verder. Maar we hebben wel een oplossing. Een oplossing. Maar als je daar natuurlijk over door gaat denken en dat gaat uitzoeken en uitproberen, dan zou je misschien wel tot een gestandaardiseerd doosje kunnen komen of iets dat dat probleem oplost. |
|     | I  | Wat is de oplossing waar jullie nu mee gekomen zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P6 | Ik weet dat niet helemaal uit mijn hoofd, maar we hebben een soort kunst, of de vloer wordt gelegd en we boren een gat van boven naar beneden waar een lichtpunt moet komen en dan komt er een speciale kunststof doos met een soort matje eroverheen en daar wordt de smeervloer op gelegd. Maar ik kan het je verstreken als je het leuk vindt hoor. Dat is wel aardig om te bedenken, maar het moet geïndustrialiseerd worden om zo'n oplossing te bedenken. Maar dat begint natuurlijk wel dat mensen door hebben dat dat dan zo'n oplossing kan zijn om die handjes in de uitvoering te voorkomen. Dat is hetzelfde dat als die wanden staan, dat ik dan toch nog een wandcontactdoosje in die muur kan maken. Ja als je dat kan bedenken, ja dat zijn wij met ons bureau aan het verzinnen. Dat doen we ook trouwens met slimme studenten, hoor. Ik ben daar druk mee bezig. Want dat zijn effecten van die slimme vloer, of die vloer waar jij nu een onderzoek aan het plegen bent. Met name de elektrotechnische kant is de moeilijkste.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Nou dat is goed om te weten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q1b | I  | Je gaf al dat dat je het als je aan tafel zit al wel eens meegeeft. Mijn volgende vraag is: op welke manier neem je zelf flexibiliteit mee in je werkproces?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P6 | Op welke manier neem je zelf flexibiliteit mee? Je bedoelt hoe daags doen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Ja precies. Dus als je met een project bezig ben of een nieuwe aanvraag binnen krijgt, ik weet niet helemaal precies hoe dat bij jullie werkt natuurlijk. Zijn er dan dingen die jij zelf meeneemt, die voortkomen uit flexibiliteit of juist niet persé voortkomen uit flexibiliteit maar wel effect hebben op de flexibiliteit.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P6 | Ja ik denk het wel. Want wij realiseren ons dat in die uitvoering, wij minder mensen in die uitvoering willen. En hoe doen we dat nou? Bij de start van een project, als we met een project aanvangen. Het is wel zo dat wij zelf meer en meer een soort voorvraag stellen voordat we überhaupt beginnen met de vraag van de klant. Dus dat we onszelf eigenlijk de vraag stellen: hebben we de vraag begrepen van de klant? Terwijl het gewoon reguliere woninkjes zijn of iets ander is. Maar kunnen we toch binnen die vraag slimmer zijn om in the end, als het bij de uitvoering komt, kosten te reduceren omdat we aan de voorkant een goeie voorvraag hebben gesteld. Klinkt misschien een beetje abstract. Maar we beginnen te vaak omdat we het altijd doen. En ik denk dat we nu in een wereld zitten, dat we niet altijd maar moeten beginnen op de automatische piloot. We moeten veel kritischer zijn, dat is hem eigenlijk, we hebben het er hier vorige week in ons team toevallig over gehad. Dat het kritisch vermogen moet toenemen in ons bedrijf. Dat is het eigenlijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | En dat doe je door te vragen wat de vraag is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P6 | Ja en ook bij jezelf na te denken. Dat de individu die bij ons werkt of bezig is met een plan, zichzelf af te vragen wacht eens even, ik doe dit nu wel, dit wordt wel van mij gevraagd, ben ik het ermee eens, klopt dit, wat zijn de argumenten, waarom doe ik dit nu eigenlijk? Dat. Meer intrinsiek wacht eens, is dit wel de juiste weg. Niet uit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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|     |    | eigenwijsheid, maar meer of in the end effectief te zijn. We doen te veel, door arbeidsdruk, vanuit automatisme. En ik denk dat dat fout is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Oké, goed om te weten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P6 | Kan je daar wat mee?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | I  | Ik denk het wel. Ik hoor, je bent de eerste persoon die ik spreek uit de wereld van installatietechniek, maar het is wel, ik denk, een herkenbaar punt binnen de hele bouw. Het teveel uitgaan van wat er normaal gedaan wordt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P6 | Verschrikkelijk is dat. Het is een groot gevaar. Ik denk zelfs dat het een afbreukrisico met zich meebrengt. Omdat de technieken, die we nu in die gebouwen inbrengen, zo anders zijn dan toen het nog een gastijdpark was. Dus er zijn veel meer risico's die mensen niet kunnen overzien, of gaan ontdekken wanneer je een keer een fout hebt. Dan krijg je weer referenties. Maar nu zitten we in een soort transitiefase. Nou dan moet je dus juist kritisch zijn als het een transitiefase is, denk ik.                                                                                                                                                                                                                                                                                                           |
|     | I  | En je zegt er zitten meer risico's, of misschien andere risico's, aan. Hoe verschillen de risico's van de installaties op dit moment ten opzichte van traditioneel slash gas?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | P6 | Nou ja, kijk als je een cv-ketel hebt. Die is per definitie 28 kilowatt vermogen. Per definitie. Maar een warmtepomp, of iets dergelijks, is anderhalf kilowatt, 2 kilowatt, misschien wel 5 kilowatt. Dus het vermogensvraagstuk en de marge die je in het verleden had, is volledig weg. En daar zit het grote verschil.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | Dan is het risico dat daar niet voldoende rekening mee gehouden wordt en dat er dan verkeerde dingen aangelegd worden? Werkt dat dan zo?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P6 | Ook dat. En kijk jij maar eens om je heen welke opleiding warmtepomp er bestaat. Op de hogeschool of de universiteit. Nou ik denk het niet. Dus we hebben er allemaal verstand van, maar we hebben geen opleiding.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | I  | Nee, precies. Oké, zo had ik er nog helemaal niet over nagedacht.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P6 | Ja, maar ik kom het tegen. Dus ik zit hier, afgelopen dinsdag had ik hier zes studenten, hartstikke leuk, ik heb me helemaal rot gelachen. Die jongens zijn blij dat ze een keer van die kamer af mogen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | I  | Absoluut, dat kan ik me voorstellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P6 | Ja dus we hebben het er zo over. Dus ik zeg joh waarom doen jullie dit eigen allemaal, dit is toch helemaal niet leuk man. Naja zo'n heel verhaal, maar daar gaat het niet over. Er zitten er allemaal omdat we het al een keer gedaan hebben. Nee, we moeten stoppen, in mijn beleving, met wat we allemaal gedaan hebben. We moeten naar een nieuwe wereld gaan. En dat is juist zo leuk met dat onderwerp dat jij hebt. Omdat er natuurlijk al duizenden onderzoeken geweest zijn naar betonconstructies. Maar het gaat nou juist dat te koppelen aan de nieuwe wereld. En de nieuwe wereld is een transitie in energie, maar ook een transitie in de inzet van nieuwe mensen. We hebben over vijf jaar hebben we geen mensen meer, vijf jaar, die in de elektrotechniek op de bouw kunnen komen. Die zijn er niet. |
|     | I  | Waarom niet?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P6 | Pensioen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Gaat dat zo hard?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P6 | Het gaat enorm hard, geloof me. Dus we gaan allemaal stekkerachtige dingen krijgen, dat je met een klik, dat eigenlijk iedereen een elektra installatie kan maken. Want een stekker kan je maar op één manier erin drukken, hé. Dus dan hoeven we niet meer na te denken dat groen bij groen moet en rood bij rood hoort. Nee we doen het stekkertje, klaar. Maar dat stekkertje, die moet wel op de vloer gelegd worden en in die wand komen. Ja hoe doe je dat? Dus het is de transitie van betonconstructies in relatie tot beperking van menskracht en geen menskracht. Dat denk ik. Ik zie de mens als de grootste drijfveer of het beter te doen.                                                                                                                                                                |
|     | I  | Oké, interessant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 1Qc | I  | Nou dan ga ik door met mijn volgende vraag. Wat zijn de huidige ontwikkelingen op het gebied van flexibiliteit die jij zit binnen je vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P6 | Naja, feitelijk, plug-and-play, stekkerverbindingen, leidingverbindingen met een A'tje en een B'tje en het A'tje past niet op het B'tje en andersom. Dus we hoeven absoluut echt niet na te denken. Je kan het moeilijk fout doen. Een beetje Ikea.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Ikea? Dat kunnen mensen ook fout doen toch?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| P6 | Ja maar dan hou je iets over, dan moet je weer overnieuw beginnen. Ja. Maar wij hebben het letterlijk gedaan. Wij hebben gezegd, laten wij nou eens een Billy kast kopen, hier met het bedrijf.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| I  | Ja, die ken ik, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| P6 | En dan gaan wij kijken of, dat is de handleiding van die kast, hoe die opgeschreven is, kunnen wij nou in Revit, BIM, een tekening produceren van een installatie in een woning met een prefab betonvloer, exact op dezelfde manier als hoe de omschrijving van een Billy kast eruitziet. Dat hebben we gedaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| I  | En?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| P6 | Iedereen lacht me uit. Ik zeg als dat lukt, dan kan jij de installatie maken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| I  | En wilde dat een beetje lukken op die manier?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| P6 | Super! Het werkt hartstikke goed. Sterker nog, je kan dan ook die tekening zo maken dat je het naar een fabrikant kan sturen. Lever mij de installatie die op onze tekening staat. Dan heb ik namelijk ook geen installateur nodig om die leiding af te zagen, want hij is dan al op maat.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| I  | Beetje modulair-achtig?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P6 | Ja, nou beetje? Zeker modulair. Want dat is Ikea ook, hè.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| I  | Ja precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| P6 | Probeer jij maar eens een kastje te kopen van 32,5 cm, dat lukt je niet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| I  | Nee. Is meestal ook niet nodig, wat dat betreft.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| P6 | Bij Ikea niet, nee. Want je bent blij dat je het kan kopen. Maar goed, dat zou in onze wereld nog wel eens een verandering kunnen zijn. Wij volgen de bouwkundige kant, de mogelijkheden die jij met je betonvloer te bieden hebt. Maar misschien is het zo dat wij dwingender moeten zijn. Dit zijn de specs die bij onze techniek horen en pas jij je maar eens aan en niet andersom.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Dat je zegt mijn installatie heeft deze afmetingen of mijn systeem heeft deze afmetingen en pas het gebouw daar maar op aan, in plaats van andersom?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| P6 | Bij wijze van spreken hè. Of past het binnen de specs van de betonvloer dat het, en als we het zo doen dan kunnen we zonder dat we iets noemenswaardigs moeten doen, kunnen we voldoen aan de specs van het andermans product.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| I  | En zou dat kunnen binnen het huidige proces? Of moet dan de samenwerking op de schop?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| P6 | Er moet nog wel wat gebeuren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| I  | Ja. Want in welke fase van een project worden jullie meestal ingeschakeld?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| P6 | Nou meestal al bij het schetsontwerp en het voorlopige ontwerp al. Maar wij zijn, ja dat klinkt een beetje arrogant, wij zijn niet helemaal te vergelijken met een gemiddeld adviesbureau. Omdat wij bekend staan op het toch even ietsjes anders denken dan anderen. Omdat ik echt werkelijk vind, in onze wereld heb je ongeloofelijk veel normen en voorschriften. Dat zul je met beton ook hebben. Maar wij hebben natuurlijk een kennisinstituut, dat heet ISSO uit Rotterdam. Dat kennisinstituut dat maakt allemaal publicaties. En die publicaties zijn gemaakt voor onze vakbroeders, voor onze vakgroep. Maar lezen we die eigenlijk ook? Kijken wat erin staat. Als publicaties over installaties, over waterleidingen, over legionella, over wat dan ook. Ik vind dat we die moeten lezen. Want dat maakt jezelf rijker om met goede argumenten de techniek in te brengen waar jij mee bezig bent. Als jij onze argumenten hoort, dan kun je ermee eens zijn of niet. Nou dan kunnen we een andere publicatie pakken die erbij past. Maar wel op basis van argumenten, maar niet op basis van dit hebben we altijd gedaan. Dat is belangrijk. Het is veel leuker om elkaar met een formule of een schema of wat dan ook te bejegenen dan ja maar dat project heb ik dit gedaan en in dat project heb ik zus gedaan. Dat schiet niet op joh. |
| I  | Dan blijf je ook hangen in wat je al gedaan hebt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| P6 | Ja precies ja. Maar je moet er wel wat meer werkt voor doen, dat wel. Je moet wel lezen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| I  | Daar moet je tijd voor hebben inderdaad, of tijd voor nemen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| P6 | Ja maar ja. Dan begint de discussie van tijd voor hebben. Dan kun je beter nee zeggen. Het is veel leuker om, als jij met die vloer en die wanden bezig bent, dat waar jij tegenaan loopt, te kijken van kunnen wij daar misschien met argumenten een oplossing voor vinden. Nee zeggen dat duurt even. Eerst een voorvraag stellen, denk ik. Nou, zo doen wij het.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |



|                                       |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
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| Q1d                                   | I  | In mijn onderzoek definieer ik flexibiliteit als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. Wat zou vanuit jouw perspectief een ingrijpende ingreep zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                       | P6 | Nou een echt ingrijpende ingreep is als ik een woning over vijf jaar of over tien jaar wil veranderen, dat ik een betonzagmachine nodig hebt om een gat te zagen in het beton. En dat ik dus echt heel veel moeite moet doen, als bewoner of als gebouweigenaar, om in te spelen op veranderende behoeftes. En kijk, nu doen we dat niet. We zeggen het wel, maar we doen het niet, omdat het namelijk heel veel energie en moeite kost. Maar als het makkelijk is, als het makkelijk aanpasbaar is, als het veranderbaar is aan nieuwe inzichten of weet jij veel hoe het er over vijf jaar uit ziet? Ik niet hoor. Ik wist niet vijf jaar geleden dat ik nu een pandemie had, dat kon ik niet verzinnen. |
|                                       | I  | Nee anderhalf jaar geleden nog niet eens.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P6 | Nee, precies. Maar dat vraagt natuurlijk wel even een totaal andere wereld van thuiswerken. Nou daar zit je.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                       | I  | Met je haperende wifi enzo.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | P6 | Ja, bijvoorbeeld. Maar ook met je omgeving, dat die last van je hebben als je zit te werken. En andersom. Dus volgens mij zijn er heel veel mensen die hun woning graag ietsje aangepast willen hebben, met een hokje erbij, hokje eraf. Misschien dat als de burens verhuizen dat je van twee woningen anderhalve woning kan maken. Ik noem maar wat. Ik zeg niet dat het gebeurt, want daar zijn we al jaren mee bezig, met dat soort verzinnsels. Maar dat komt omdat het nu te complex is.                                                                                                                                                                                                             |
|                                       | I  | Dus als het simpeler in elkaar zit als systeem, dan...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | P6 | Dat zou mooi zijn, ja. Ik ben in de Ikeafabriek geweest. Ik ben in die fabriek van 70000 vierkante meter geweest. En ik zie hoe ze dat maken. In hout en allerlei constructies. Dus als het nou in hout kan, waarom zou het dan met betonelementen niet kunnen, denk ik dan. Maar het gaat ook over het geloof in een aanpak. Ja en niet met alle winden meewaaien.                                                                                                                                                                                                                                                                                                                                        |
|                                       | I  | Je hebt voortrekkers nodig die er echt voor gaan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                       | P6 | Ja. Daarom vind ik het super stoer wat Van Wijnen doet nu met die fabriek in Heerenveen. Ja jongens, als het echt zo is en je gelooft erin. Ja dan krijg je die kritiek van anderen. Dat is mooi, want die zijn dan bang.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | I  | Ja als het werkt, dan heb je iets moois in handen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | P6 | Ja. Dat is ook geloven erin. Steve Jobs van Apple geloofde er ook in. Hij heeft niet gevraagd of je de telefoon mooi vond, hij is er gewoon mee gekomen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                       | I  | En nu heb ik er zelf ook één.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                       | P6 | Ja ik ben ook zo'n sukkel die dat heeft, ja. Dat kost elke keer meer als ik een beetje een nieuwe wil hebben Het wordt ook nooit goedkoper.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | I  | Dat valt tegen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Q2a                                   | I  | Nou dit was mijn eerste topic. Mijn tweede topic. Nou mijn eerste topic gaat al een beetje over vloeren omdat dat er toch al een beetje in zit. Maar nu ga ik echt in op de vloeren. Daarbij is mijn eerste vraag: wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                       | P6 | Wat een vloer voor mij is? Nou dat zou waarschijnlijk een heel traditioneel antwoord zijn, ben ik bang. Dat is een vloer is voor mij waar ik op kan lopen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                       | I  | Dat is wat een vloer een vloer maakt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | P6 | Lopen, ja. Want een vloer kan ook een perron zijn, van een trein bijvoorbeeld. Nou ik denk dat dat het wel zo'n beetje is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                       | I  | Oké duidelijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | P6 | Maar als ik naar mijn eigen gebouw kijk, dan is mijn vloer ook een onderdeel van mijn klimaatstelsel. Dat kan ook. Maar dan moet ik er wel in verblijven, anders heb ik niets aan dat klimaatstelsel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | I  | En is dat klimaatstelsel, is dat een belangrijk onderdeel van een vloer?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                       | P6 | In mijn geval wel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | I  | In jouw geval, is dat omdat je binnen bent, of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                       | P6 | Nou het maakt een onderdeel uit van mijn energiezuinigheid van het gebouw. Maar ook gewoon dat het accumulerend vermogen van de betonvloer heb mee laten tellen in mijn totale klimaatstelsel. Dus ik heb echt gekeken wat is het accumulerend vermogen van                                                                                                                                                                                                                                                                                                                                                                                                                                                |



|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     |    | die vloer. Als een soort PCM [Phase Change Material] systeem. Zo zie ik hem ook eigenlijk. Ik zie hem echt als een energieopslag ding in mijn gebouw.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | I  | Interessant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P6 | Het heeft allerlei nadelen hoor, overigens. Maar goed. En ook voordelen, maar ook nadelen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I  | Geef eens een nadeel?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P6 | Dat de vertraging, de ontladingstijd, de ontlading van de vloer, dat je daar beter over na moet denken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | I  | Dat heeft te maken met de massa?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P6 | Ja. Daar weten we nu veel meer van dan toen we dit gebouw gemaakt hebben. En ik heb er toen ook minder goed over nagedacht. Maar ik verzeker je, met dat hoe het nu is, gister was het 24 graden en een dag later is het iets kouder. Nou dan stik je hier de moord hoor, als je niet uitkijkt. Dus je moet wat doen. Dus dat ontladen, ik vergelijk het met onze mensen hier met één vierkante meter waxinelichtjes. Als je die aan doet wordt het hartstikke warm. Maar als je ze uitblaast, dan is het ook vrij snel weer koel. Nou en kan je nou die vloer, die betonvloer, onderdeel uit laten maken van het energieopslag systeem. Dat op je dak een zonlichtsysteem ligt en die ga je lekker opladen de hele dag. En daar heb ik 's avonds hartstikke veel plezier van. Ik zie een beetje, ik zie er een wereld in verschijnen. Maar of dat zo is, dat weet ik niet. |
|     | I  | De vloer als opslag.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P6 | Ik weet het wel zeker, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I  | Daar heb je massa voor nodig, neem ik aan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P6 | Ja, dat is een betonvloer al gauw, hé.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Dat is dan in dat geval een belangrijke eigenschap.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q2b | I  | Nou mijn volgende vraag is: kun je mij vertellen over de huidige staat van flexibiliteit van vloeren? Het sluit aan op wat we al eerder besproken hebben, maar nu dus echt specifiek over vloeren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | P6 | In de dagelijkse praktijk bedoel je?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P6 | Ik probeer even te bedenken wat je precies bedoelt. Of het veel toegepast wordt bedoel je, of dat het ook veel gebruikt wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Ja, zeg maar, in welke zin je het tegenkomt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P6 | Het is al heel gauw een onderwerp als er heel veel repetitie is en volume. Dus een projectje van dertig woningen, kom ik het niet zo gauw tegen. Maar worden het er meer dan zestig en er zit weinig variatie in de woningen, dan wordt het al gauw een onderwerp. Dan zou het zomaar eens naar de positieve kant kunnen uitvallen. Dus het is altijd een economisch vraagstuk. Niet vanuit flexibiliteit, puur financieel gedreven, maar wel op basis van volume.                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | En wat is het aan een groter volume dat het dan opeens wel interessant wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P6 | Ik denk dat het gaat tellen na zestig, zeventig woningen gaat het wel tellen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | I  | En waarom gaat het dan tellen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P6 | Omdat het te maken heeft met bouwsnelheid, dus bouwplaat kosten zouden wel eens terug kunnen lopen als je dat voor elkaar kan krijgen. Het kan meetellen in stikstof vraagstuk. Met je rijbewegingen. Je hoeft natuurlijk al dat beton niet naar het werk te vervoeren. Die auto's hoeven niet te rijden. Ik denk dat daar een beetje een soort wereldje zit. Ik heb het niet helemaal uitgezocht, want dat is niet helemaal mijn vakgebied. Maar ik zou me zomaar kunnen voorstellen dat stikstof en vrachtwagens en transportbewegingen en locatie waar je minder overlast, allemaal van die dingen, snel klaar zijn. Aan het spoor bouwen kan je beter met prefab doen dan dat je een jaar staat te gieten.                                                                                                                                                              |
|     | I  | En hoe komt flexibiliteit hier dan bij kijken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P6 | Nou dat is in de dagelijkse praktijk eigenlijk geen onderwerp. Daar hadden we het net over, hé. Dat is nog, ja, ik hoor het nooit.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I  | Oké, nou dat is jammer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P6 | Maar wel in het kader van voor straks, nadenken over menskracht en dat soort dingen. Dan gaat dat, dan zal het meer gaan spelen. Maar nu? Ja er zijn partijen mee bezig. Ik heb een enorm groot project in [grote Nederlandse stad], lopen op dit moment. [projectnaam] heet dat. Een fantastisch ding. Ongelofelijk moeilijk. Het zit aan het spoor,                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

|     |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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|     |    | aan de corridor van [grote Nederlandse stad], dus druk drukke verkeersweg. En [wooncomplex] in [grote Nederlandse stad] dan. En waarom [wooncomplex] in [grote Nederlandse stad]? Omdat we dachten met prefab en ook op deze manier, dat het meebewegen van de behoefte van studenten, het zijn studenten en young professional woningen die worden gemaakt. Dat kan, over tien jaar kunnen er minder studenten zijn, dan maak je er een twee kamer woning van. Op die manier, weet je wel. Daar wordt wel over nagedacht, in die wereld. Maar het is niet een dagelijks voorkomend ding.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | I  | Het zijn speciale projecten waar er dan meer aandacht voor is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P6 | Ja, er komt meer aandacht omdat ze zien dat je door schaarste van mensen ander moet gaan denken, anders mis je de boot. Dus er zijn andere actoren die daartoe drijven dan dat je zo graag een flexibele woning wil maken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | I  | Het heeft te maken met aanbod, zal ik maar zeggen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P6 | Aanbod, maar ook voor straks, ja met aanbod.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I  | Ja aanbod van mensen dan in dit geval.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P6 | Ja ik denk echt dat dat wordt topic nummer één. Daar ben ik van overtuigd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Q2c | I  | Als we het over de toekomst hebben, dat sluit wel goed aan bij mijn volgende vraag. Welke trends zie je in de ontwikkelingen van installatietechniek, die invloed zouden kunnen hebben op het ontwerp van vloersystemen in de toekomst. Dat is niet persé flexibiliteit gerelateerd, dat kan van alles zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P6 | Letterlijk assemblage, assembleren. Ja. Niet meer monteren en installeren, maar assembleren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I  | In elkaar zetten in plaats van?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P6 | Ja. De Billy kast, hé. Dat schroefje past precies in het juiste gaatje.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Oké. En hoe zou dat effect hebben op een vloersysteem?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P6 | Dat er al voorzieningen zijn opgenomen zodat ik makkelijk kan klikken, met mijn wanden en mijn toiletpot en mijn wastafel. Dat het allemaal precies, hé die schroefjes die zitten er al.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | Je hoeft alleen maar aan te haken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P6 | Ja, niet nadenken. Gewoon de tekening volgen. Letterlijk Billy.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | De Ikea, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I  | Mooi. Dan kom ik bij mijn laatste topic alweer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P6 | Ik hoop niet dat ik heel veel verwarring veroorzaak nu.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Nee hoor. Nee. Ik denk dat zaken als modulariteit voor veel mensen een thema zijn op dit moment. Alleen, wat ik ook al zei, dat veel mensen aangegeven hebben dat de bouw vrij traditioneel is. Dus het is wel opvallend dat dingen veel gesignaleerd worden, maar dat er toch nog niet zoveel aan gedaan wordt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P6 | Dat is typisch Nederlands, geloof ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | I  | Het is in ieder geval iets wat me opvalt. Dat de oplossing er nog niet echt is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P6 | Als je naar de hotelbranche gaat kijken, bijvoorbeeld bij Van der Valk, ik noem er even één. Neem maar van mij aan, die snapt als je modulair gaat bouwen en prefab gaat bouwen, dat het in de euro's enorm scheelt in kosten. Al die kamertjes zijn allemaal hetzelfde joh. Het enige verschil is dat het dekbed er anders uit ziet of dat er een andere foto aan de muur hangt. Maar al die badkamers zijn echt allemaal hetzelfde. Die snappen echt wat een euro waard is. Dus in andere bedrijfstakken is het allang doorgevoerd. Wij hebben een project in [middelgrote Nederlandse stad], dat heet [projectnaam]. Daar hebben tweeëntwintighonderd studentenwoningen gemaakt. De laatsten worden nu opgeleverd. Maar bij de eerste 900 moest het heel erg energiezuinig zijn. En moet je voorstellen 900 studenteneenheden van 26 m2 met een badkamertje in een betonconstructie. Hoe doe je dat slim? Ik denk ja... Toen ben ik letterlijk naar een cruiseschipbouwer geweest in Hamburg. Over prefab gesproken. En flexibiliteit. Dat is geen beton. En dan kunnen zomaar vierduizend mensen hun eigen hutje krijgen. Dat is gewoon een dorp dat op zee ligt. Ongelofelijk veel van geleerd. Gewoon eens hele andere bedrijfstakken te kijken, hoe doen zij het eigenlijk. Nou, cruiseschip! |
|     | I  | En kun je een voorbeeld geven van wat je geleerd hebt van het cruiseschip?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P6 | Nou dat is voornamelijk dat die bood van A naar B met zo min mogelijk energie moet varen. Want dat kost allemaal geld. En kan kunnen ze de tickets goedkoper maken als je minder overhead en minder kosten hebt. Dus we denken dat ze daar niet op letten, maar daar letten ze wel degelijk op. Met name het warme tapwater. Want iedereen heeft                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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|----------------------------------------------|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                              |    | zijn eigen doucheje. En je hebt gelijk warm water. Dus er zit een enorme warm tapwater voorziening achtig ding op die bood. Nou rioolzuivering, rioolwater wordt gebruikt, warme wordt eruit gehaald, is nu pas een thema bij ons in de bouw. Warmte uit rioolwater. Nou er komt heel veel rioolwater in zo'n boot. En er moet zo min mogelijk energie dat warm water gemaakt worden voor die douches. En er staat letterlijk automotoren in die warm water produceren. Ik ben via dat idee ben ik bij Pon in Leusden terecht gekomen. Pon is de importeur van Audi, Volkswagen, dat soort dingen. En via die club heb ik motoren gevonden, automotoren. In [projectnaam] staan echt automotoren van Porsche, Porsche staat erop. Die auto zet je aan, die gaat nooit meer uit. En die blijft draaien. De emissie is daardoor heel laag, want die automotoren hebben hele lage emissies. Dat moet ook door alle regelgeving in de wereld. Maar wie verzint nou dat je een gebouw gaat verwarmen met een automotor. Ik niet! Maar ik zag het op die boot. Vanaf dat moment dacht ik wacht even als we een vraagstuk hebben, hoe doet een ander dat? Hoe doen ze dat bij een bakkerij, een industriële bakkerij? Hoe doen die daar hun broodjes bakken? Dus, hé, ik neem onze mensen ook lettelijk mee om bij andere sectoren te zien hoe het daar gaat, om efficiënt te worden. Niet zo zeer naar de technische oplossing, maar wel nadenken over de efficiëntie. Nou en dat heeft me enorm veel gebracht. En het is ook enorm leuk, echt leuk! |
|                                              | I  | Dat geloof ik! Klinkt tof.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                              | P6 | Mijn cruiseschip verhaal is mijn metafoor voor anders denken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                              | I  | Het klinkt inspirerend.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                              | P6 | Nou als je in een boot staat waar vierduizend mensen kunnen verblijven en feesten, dat is eng om te zien hoe groot dat is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Topic 3: Challenges and opportunities</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Q3a                                          | I  | Ik ga wel even door naar mijn laatste topic, ook omdat ik jou anders te lang van je tijd beroof. Dat zijn kansen en uitdagingen. Dus er komt een tweeluik aan vragen. Eerst wil ik het graag over de kansen en hebben en dan over de uitdagingen en obstakels. Dus de eerste vraag is: welke kansen zie je voor flexibiliteit met betrekking tot installatietechniek en vloersystemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                              | P6 | Nou een kans die ik daarvoor zie. Dan vanuit de vaagkant, lees: Van Wijnen, schrap beton. Dat er veel meer een relatie gelegd wordt tussen leveranciers of fabrikanten. De installateur, die moet er tussenuit, die levert niks.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                              | I  | Die levert handwerk?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | P6 | Dat zijn de handjes, ja. De goede installateurs daargelaten. Maar ik denk dat de relatie, de mogelijkheden die een fabrikant heeft, die moet je ontdekken om te kijken wat jij weer kan doen met betonconstructies. Bijna alle Nederlandse fabrikanten in de installatietechniek werken wereldwijd. Maken een product voor de hele wereld. Echt niet alleen voor Hogeveen of Lutjebroek, echt niet, nee. Daar kan van je leren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                              | I  | Dus de kansen zie jij in een nauwere samenwerking?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                              | P6 | 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | I  | Mooi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                              | P6 | En ik zie onze rol daarin, onze rol zal daar ook in gaan veranderen. En ik zie onze rol veel meer als een soort kennisverbinder tussen wat er gemaakt moet worden en de regelgeving tussen alle normen en voorschriften, om veel digitaler ons ontwerp te kunnen maken. Want ik ben van mening dat, alle sommetjes die we moeten maken, kan veel digitaler. Dat zie ik onze wereld als een kans. Zodat ook wij met minder mensen meer productie aan kunnen. Omdat we veel meer kunnen digitaliseren. Ik weet niet of je dat parametrische ontwerpen al een beetje mee krijgt? Ik geloof daarin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                              | I  | Ik ben bekend met parametrische ontwerpen vanuit mijn studie. Ik ken het alleen nog niet zo goed in combinatie met installatietechniek?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                              | P6 | Nou dat is nog heel erg bepekt. Maar als ik een gebouw parametrisch ga ontwerpen, waarom kan ik daar mijn installaties niet in zetten? Daar moet toch lucht in. Maar daar moet je over nadenken. En dat zie ik als een verbindende factor. En dat heeft een eindtijd. Maar dat zien we dan wel. Maar door die digitalisering, daarmee te beginnen, en vanuit Delft wordt daar heel veel energie in gestopt, dat weet ik. Ja ik geloof daarin. Nou dat hoef ik echt niet te gaan vertellen tegen de installateurs hoor, laat staan mijn vakbroeders. Die denken die is gestoord. Nou dat kan wel zijn, laat mij daar maar lekker mee. Ik geloof erin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | I  | Wat doet hun denken dat het gestoord is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

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|------------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | <b>P6</b> | Ik denk dat dat alleen maar gedreven is uit bedreiging, dat ze straks niets meer te doen hebben. Nou, ja. Je zal toch het leven hebben gehad dat je droom is een postbode zijn. Ik kom de postbode tegenwoordig helemaal niet meer tegen joh. Er is een heel architectenbureau uit Antwerpen, AVG heet dat. Fantastisch mooi, groot architectenbureau. En die hebben ook als metafoor in hun pay-off staan: de enige constante in het leven is de verandering. En dat is ook zo.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|            | <b>I</b>  | En daar moet je in mee gaan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|            | <b>P6</b> | Ja als je niet meegaat verandert het toch.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Q3b</b> | <b>I</b>  | Nou dan wil ik de andere kant van deze vraag nog stellen: welke uitdagingen of obstakels voorzie je voor flexibiliteit met betrekking tot installatietechniek en vloersystemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|            | <b>P6</b> | Traditioneel gedrag van de aannemer. Dat die geen openheid van zaken geeft hoe zijn calculatie in elkaar zit en per definitie zegt prefab, of zoiets, is duurder dan ik gewend ben. Je krijgt die openheid nooit.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|            | <b>I</b>  | Dus je weet niet waar dat 'duurder' in zit, in dat geval?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|            | <b>P6</b> | Inderdaad. Ja. En dat is de grootste bedreiging.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|            | <b>I</b>  | Oké.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|            | <b>P6</b> | En ik denk wel de enige.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|            | <b>I</b>  | De enige?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|            | <b>P6</b> | Ik denk het wel. Want als het je lukt. Je zult er echt over na moeten denken van hoe kan ik nou het gedrag veranderen of in ieder geval bewerkstelligen dat de partij die hiermee te maken heeft denkt hé dat is leuk, laat ik er eens aan gaan rekenen. Kan ik er misschien minder bouwplaats kosten, minder keetkosten, minder mensen in de uitvoeren, minder dit, minder dat, minder zus, minder rijbewegingen, ga zo maar door. Dat dat een soort mindset verandering wordt om dat toch wel objectief naar te blijven kijken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|            | <b>I</b>  | Dus je zou graag willen weten wat er meegenomen wordt in die kostenberekeningen? Om te kijken of daar ook al die rijbewegingen en dat soort dingen in meegenomen wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|            | <b>P6</b> | Ja. Ja, er is een keten aan plussen en minnen en die plussen en minnen zijn essentieel om die veranderingen voor elkaar te krijgen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|            | <b>I</b>  | En als je niet ziet waar die plussen en minnen zitten, dan is dat ingewikkeld?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|            | <b>P6</b> | Dan krijg je belemmering, dan krijg je per definitie belemmering. Dat maak ik, dat is dagelijkse praktijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|            | <b>I</b>  | Dat je ertegen aanloopt dat je gewoon een 'nee' krijgt, zonder onderbouwing, als het waren?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|            | <b>P6</b> | Ja. Het hele bizarre wil nu. We hebben een project dat heet dan [projectnaam]. En we hebben gezegd, we gaan niemand bevragen op basis van concurrentie.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|            | <b>I</b>  | Wat bedoel je daarmee?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|            | <b>P6</b> | Nou we gaan installateurs en toeleveranciers gewoon een vraag stellen met een goed verhaal, een goed uitgezocht verhaal, en vragen, bijvoorbeeld aan jou, wil je met ons meedoen, wil je betonvloeren leveren voor dit project. Dit zijn mijn specificaties. En je zit één op één aan tafel en we gaan niet onderhandelen over de prijs. Dus wij gaan ervanuit dat jij, jouw verdienmodel hou je intact, tenzij je er [onverstaanbaar] over bent en nog meer geld wil, dat zien we gauw genoeg. Dus als je objectief, gewoon je boekhouding op tafel durft te leggen, wat je verdienmodel is. En onderaan de streep snapt iedereen dat je wat moet verdienen, anders kan je je bedrijf niet laten runnen. Dat zijn we echt aan het doen. En het gekke is dat ik 20% kostenbesparing heb weten te bereiken. Dus al die opslagen en dingen. Het idee dat iemand niet hoeft te rekenen omdat het concurrentie is en gewoon, ik ben aan het rekenen voor een echt project, dat motiveert heel anders dan dat je één van de duizend bent, bij wijze van spreken. Dus er zit ok een stukje psychologie in, dat echt telt. |
|            | <b>I</b>  | Het idee dat je meer aan het samenwerken bent?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|            | <b>P6</b> | Ik ben benieuwd hoeveel offertes Van Wijnen maakt, die ze niet krijgen. Maar dat is allemaal geld weggooien. Want zo'n hele calculatie voor een beetje project is echt serieus geld voor een aannemer. Nou dat kan je beter in, zeg maar, dat jij ietsjes meer kost, uitgeven. En dan is het is het [onverstaanbaar] toch nog goedkoper.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| I  | Als je van tevoren al meer zekerheid hebt, dat je er vanaf het begin meer in kan investeren, als het ware?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| P6 | Dat vind jij toch ook leuker, als het concreet is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| I  | Ja tuurlijk, je wil ergens naartoe werken uiteindelijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| P6 | Precies. Nou, dat vinden wij eigenlijk allemaal. Dit heb ik niet helemaal van mezelf. Ik ben getipt een paar jaar geleden door een antropologe, die had ik ingeschakeld. Ja hoe kom ik daar nou? Ik moest iets bereiken en dat lukte niet zo goed. En toen ben ik geconfronteerd met een antropologe, ik zal het nooit meer vergeten. Super, man, super! Heel ander aankijken, hoe jij denkt. Daar heeft zij over geleerd, ik weet dat niet, ik denk het te weten. Nou forget it. Je wordt, je krijgt tips en trucs om anders met andere mensen om te gaan dan ik altijd gedaan had. En dat heeft echt bij ons een verandering veroorzaakt. Het heeft even geduurd, maar ik weet zeker dat het daarvan vandaan komt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| I  | En dat is dan meer samenwerkend, is dat wat je er meer uitgehaald hebt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| P6 | Samenwerken, maar ook om te voorkomen dat je het fenomeen veronderstellingen uitbant. Die veronderstellingen zorgen alleen voor misverstanden en miscommunicatie. En dat heb je helemaal niet door joh. En als je bewust bent, dan ga je ook kritischer zijn op wat je krijgt en je gaat het checken, wat je krijgt. We checken normaalgesproken helemaal niks joh, we doen het gewoon. Met alle gevolgen van dien. Oh ja dat hadden we beter anders kunnen doen. Ja dat had je moeten controleren aan het begin. Ja dat weet je toch? Ja ik was ervan uitgegaan dat jij dat zou doen. Ja jij zou dat toch doen? Ja! Nou dan heb je elkaar dus niet begrepen. Allemaal van die lulverhalen krijg je dan allemaal.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| I  | En ga je dan werken met checklists, of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| P6 | Op voorhand niet, want een checklist is ook weer beperkend. Uiteindelijk. Maar wel met een processchema, dus je moet wel je proces in beeld hebben. Maar checklistjes, nou dat is een administratieve bezigheid die je... Het gaat, nadenken over hoe je met elkaar om wil gaan. En we denken allemaal, dat als we bij elkaar komen voor een project, dat we een team zijn. Hoezo? We hebben nog niet eens een voorstelrondje achter de rug en dan zijn we een team? Nou, dus wat wij nu voor een ander project hebben gedaan. Het zijn allemaal probeersels, hè. Ik denk weet je wat, ik ga een studentenvereniging vragen om in een skiff van acht personen, dan gaan we gewoon roeien. We kennen elkaar toch allemaal? We vinden toch allemaal dat we het goed doen? Nou kost haast niks, hé. Voor vijfhonderd euro staan die gasten allemaal lekker een barbecuetje te maken. En er zijn twee van die studenten die gaan ons dan helpen om, met drie boten, ons in een boot te krijgen. Nou, ga maar eens roeien met zijn achten. Ik verzeker je, dat gaat in de eerste vijf minuten al mis. Het is super geweest! Maar ook het inzicht wat je ervan krijgt. En dat heb je niet door op het moment zelf, dat ga je pas later, zie je dat. En dus kennelijk gebeurt er ergens iets in je hoofd over samenwerken en hoe je dat moet doen en ook gewoon zeggen dat je het niet kan. Dat is toch veel leuker om te zeggen? Ik vraag aan iedereen hulp! Ik zeg op voorhand al dat ik het niet kan. Nou ik krijg altijd hulp! Ideaal toch? Ik wel hoor. Heb ik ook geleerd overigens hoor. Wees daar open voor en vraag! Dat je gewoon zegt, ik kan het niet. Of ik weet het even niet. Of help, kan je me even helpen? Nou dat mag je in dit bedrijf rustig zien. We zijn laatst ook geïnterviewd. Iedereen is hier onafhankelijk geïnterviewd en dan zou ik wel horen hoe dat precies gegaan is. Het heeft echt, de laatste drie vier jaar hebben we eraan gewerkt, om juist, wat zeg ik met die skiff acht voor mekaar te krijgen, dan, je kan niet een egoetje in zo'n boot hebben, dan gaat het ook fout. Weg met die ego. Waarom eigenlijk? Het klinkt zo simpel, maar dat is het niet. Het is echt moeilijk! Daarom denk ik, die verandering en over die vloer en als dat moet, als die aannemer door heeft dat het echt anders kan en dat het die resultaten kan boeken, dan gaat ie. |
| I  | Dus de aannemer moet ook meer teamspeler willen zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| P6 | Zeker. Ik heb zelf ook meegedaan aan die boot. En ik dacht, ik ga niet bij die stuurvrouw zitten, want dan ben ik de eerste, dan ben ik de lul. Dacht ik, hè. Nou dat is de grootste fout die ik heb gemaakt, want ik ging achterin zitten. En dat moet je echt niet doen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| I  | Nee?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| P6 | Je kan beter zorgen dat je de eerste bent!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| I  | Jij moet je dan op iedereen aanpassen of niet?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| P6 | Verschrikkelijk! Ja echt. Ja. Dus, niet over nagedacht! Je lacht er misschien om, maar het is echt. Je hebt dat soort simpele dingen nodig, want het is eigenlijk simpel. Nou en                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |



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|  |  | dat simpel denken, dat is eigenlijk het moeilijkste wat er is. Hoe krijg ik die wandcontactdoos in die betonwand, zonder dat ik iemand op de vloer hoeft te hebben? Het is gewoon een stom stopcontactje, waar hebben we het nou over? Ja. Een dingetje van 65 euro, nou zoek het uit. |
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Table B.10: Transcription interview P7

|                                          |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                              |
|------------------------------------------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| <b>Interviewee</b>                       |           | P7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Consultant at a medium-large Dutch building services company |
| <b>Date and time</b>                     |           | April 7 <sup>th</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 11:00                                                        |
| <b>Topic 1: Flexibility of buildings</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                              |
| <b>Q1a</b>                               | <b>I</b>  | Kun je me vertellen over de huidige staat van flexibiliteit in de installatietechniek?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                              |
|                                          | <b>P7</b> | Je hebt natuurlijk verschillende... Praten we echt over woningbouw of ook utiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                              |
|                                          | <b>I</b>  | Ik ben persoonlijk bezig met woningbouw, maar mochten er interessante dingen uit de rest van de bouw zijn, hoor ik dat ook graag.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                              |
|                                          | <b>P7</b> | Nou kijk, in de woningbouw is het natuurlijk altijd dat je vrij star bent, omdat het allemaal in beton ingegoten system zit. Je hebt natuurlijk ook houtbouw, dat is tegenwoordig wel heel erg in. Daar ben je natuurlijk wat flexibeler om mee om te gaan. Kijk utiliteit is vaak een blikken doos, wat betreft opbouw, er zit natuurlijk een systeemplafond. Daar ben je wat flexibeler in, in aanvang eigenlijk. Dus ik denk dat we utiliteit even parkeren, waar daar kan je altijd redelijk flexibel zijn. Nou in woningbouw heb je natuurlijk verschillende systemen, waar je woningbouw kan maken. Nou je noemde bijvoorbeeld al hout. Dat is natuurlijk niet heel erg gebruikelijk, dat dat gebeurt. Wij hebben wat projecten bijvoorbeeld gedaan met [kleine Nederlandse ontwikkelaar van bouwsystemen], dat is een houtbouwer. Nou en dan ben je wel redelijk flexibel. De wanden kan ik alles in BIM maken. Het is hout, je zaagt ze open, je kan alles veranderen. Het wordt weer dichtgemaakt en het is klaar. Dat geldt ook voor de plafonds. Het zijn vaak losse plaatjes, het lijkt een soort systeemplafond, waardoor je eigenlijk alles tussen de plafonds kan aanleggen. Het enigste nadeel is, wat je daar hebt, is de balken die je daar tegen komt. Daar mag je niet zomaar ongelimiteerd grote gaten in zagen, dan zakt het huis in mekaar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                              |
|                                          | <b>I</b>  | Nee dat moet je niet hebben.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                              |
|                                          | <b>P7</b> | Nee, dus dat is een systeem. Van oudsher maakten wij bijvoorbeeld woningen met kalkzandsteenwanden, kanaalplaat of breedplaatvloeren en GIBO-binnenwanden. En dan ben je tot het moment dat de vloeren erin gaan, ben je eigenlijk heel flexibel, omdat alles kan je omfresen, in ons vakgebied kan je alle kanten op. Totdat die volgesmeerd is en dan ben je eigenlijk helemaal klaar, dan kan je niet veel meer. Dan kan je nog een puntje op een paar centimeter omhalen en dan houdt het wel op. Stopcontacten vallen dan nog wel mee. Maar bijvoorbeeld een data inzetpunt, ja, een kabel kun je soms niet meer vervangen door het aantal bochten wat erin zit. En qua afvoer of lucht moet je natuurlijk heel weinig bochten erin hebben, anders gaat het suizen of het gaat er gewoon niet meer doorheen. Dus dat is eigenlijk wat we, denk ik de afgelopen twee drie, ik draai niet vijftig jaar mee, afgelopen twee vierentwintig jaar, hebben we dat eigenlijk veelvuldig toegepast dit systeem. Nee dan heb je eigenlijk nog, in de hoogbouw had je gietbouw systemen. Maar dat waren vaak wanden die in het werk gestort worden, die maak je eigenlijk op de werkplaat in mekaar. Nou dan ben je eigenlijk, als die wand gestort is, dan ben je niet meer flexibel. Dat, dus ja. En eigenlijk is het, breedplaatvloeren, in het werk gestorte vloeren, dan ben je eigenlijk heel snel niet meer flexibel. Dus eigenlijk de heilige graal in ons vakgebied is eigenlijk heel lang geweest om te proberen flexibel te zijn. Nu is op één gebied, op elektra gebied, is er een keer een KISS systeem geweest, van Hager. Dat waren eigenlijk plintgoten rondom, waar je dan eigenlijk stopcontacten in kon maken en die kon je dan schuiven over de plint. En dan legde we in de vloer een bepaalde box neer en die box die ging dan naar de meterkast en dan konden we eigenlijk redelijk flexibel alles indelen. Ook bijvoorbeeld in de keuken, daar legden we een box naartoe, en dan maakte het niet uit wat voor mensen of wat voor keukens ze kochten of wat voor apparatuur, dat konden ze tot op het allerlaatste moment beslissen. Het enigste nadeel wat dan wel was. De lichtpunten waren wel heel erg vast, daar kon je niks mee doen. Weet je wel, je moest echt bepalen waar kwamen de lampen of je moest je een verlaagd plafond eronderdoor maken. Alleen |                                                              |



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|    | <p>sinds een paar jaar is er het bouwbesluit en moeten plafonds minimaal 2,60 2,80 zijn, ja dan heb je heel weinig ruimte meer om een verlaagd plafond te maken. En mensen vinden, ik ben zelf verkoper ook, dus mensen zeggen altijd, 'royaal' noemen ze dat, als er hoge plafonds, dan oogt het dat een huis veel ruimer is eigenlijk. Dus daar moet je eigenlijk zo min mogelijk aan tornen. Dus dat was eigenlijk een tussenoplossing voor het flexibele systeem. Op dit moment worden er natuurlijk heel veel kantoorpanden verbouwd tot woningen. Eigenlijk is dat natuurlijk een vorm van transformatie of renovatie. Nou en daar doen we met flexibele systemen, daar stekkeren we tegenwoordig. Dat heet stekkerbare systemen en dat, eigenlijk van één woning maak je een soort, maak je het karkas. Dus van metal stud wanden, dus van metaal en gips, en eigenlijk één woning meet je helemaal uit. En eigenlijk dan maak je allemaal, een spin noemen wij dat, van stekkers. En daar ben je redelijk flexibel in. Je boort een gat, je hangt er een stekker doorheen, je klikt het in mekaar en je bent eigenlijk kan je verder gaan. Dus dat is op dit moment het meest flexibele systeem dat we kunnen eigenlijk. Kijk en wij zijn best wel vooruitstrevend, wij houden onze markt wel in de gaten. Wij hebben, denk ik, vijf zes jaar geleden een systeem gedaan met een flexibele vloer, ik weet niet meer hoe die heette precies. Maar dat was een soort breedplaatvloer, alleen daar zaten allemaal blokken in en een soort geulen en daar kwam een soort deksel op en in de deksel zat standaard de vloerverwarming gestort. Dus dat deksel kon opgetild worden in bepaalde delen en daaronder kon je bijvoorbeeld je leidingen leggen en dan kon je bijvoorbeeld je stekkers leggen zoals we het nu boven in de plafonds doen. Maar dan kon je ook bijvoorbeeld je riolering kon je aanpassen en je kon je mechanische ventilatie. Dat was vroeger een metalen systeem, je afzuiging, maar tegenwoordig gebruiken we daar een groen systeem voor van Dyka, het heet Dyka air. Het zijn groene leidingen, die kun je flexibel in de vloer maken, dus dan ben je wat flexibeler ook. Want je hebt ook te maken met de wapening in de vloer hè. Het moet ook stevig zijn. Dus je moet wel bepaalde dingen kunnen doen. Dus dat is op dit moment de meest flexibele vorm die wij kunnen.</p> |
| I  | Oké, er wordt wel actief over nagedacht dus?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| P7 | <p>Arbeid is natuurlijk in onze branche een groot goed. Wij werken eigenlijk hoofdzakelijk met Nederlandse mensen en wij huren dan wel eens andere mensen in. Maar wij vinden het heel belangrijk dat Nederlandstalige mensen op de bouw staan. Dus mensen die wij hebben, ja vroeger was dat het klootjesvolk van de bouw zeg maar, maar wij zeggen nu tegenwoordig die jongens gaan naar een hoger niveau. Dus die jongens die willen leidinggeven, maar die moeten dat uitleggen aan mensen die minder verstand hebben, zeg maar, niet denigrerend bedoeld, maar die slecht de taal kunnen. Dus je moet eigenlijk iets simpels kunnen overdragen, zodat ze het eigenlijk heel makkelijk kunnen maken. Dus zo'n systeem voor stekkeren, dan doen we nu bijvoorbeeld met kleurtjes. Dus de kleur rood.. Bijvoorbeeld [leverancier], daar doen we dat systeem mee en die kan bijvoorbeeld het allemaal met kleurtjes al aanleveren vanuit de groothandel. Dus dan komt het op de bouw in doosjes per woning en dan zit daar gewoon standaardlengtes in. Dan maak je het gewoon simpeler, want dan hou je eigenlijk de monteurs die er verstand van hebben, hè, verstand van het vak, die ook onderlegd zijn om storingen te onderkennen en die het aan mogen leggen. Want wij moeten een onderricht persoon aanwijzen voor die installaties. Ja die houd je dan voor de leidinggevende taken en de mensen, de handjes eigenlijk zeg maar, die sluiten het dan aan. En daarom is flexibel ook wel makkelijk want dan is het ook, stel dat er een fout in zit, of iemand maakt een domme fout, dan kan je het ook heel makkelijk oplossen.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| I  | Dat is niet te doen als het ingestort is natuurlijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| P7 | <p>Nee, en normaliter zou je monteurs die nu leidinggeven, die zouden eigenlijk dat werk in het beton maken. Maar ja die zijn er weinig meer, die zijn uitgestroomd. Die maken we nu wat overkoepelende en we laten anderen het werk doen. En die jongens die normaal nu leidinggeven, die wisten wel waar ze mee bezig waren maar heel veel nu niet. Dus je hebt een verstopping of zoiets, ja dan zoek je in het beton, moet je alles kapot hakken. Dat kost uren en uren zijn het belangrijkste goed. Wij rekenen voor een appartementje bijvoorbeeld 40 tot 50 uur. Ja, als er een verstopping zit, zijn die jongens gewoon een halve dag aan het zoeken bij wijze van spreken. Nou dan moeten ze het ophakken, moeten ze het weer aansmeren. Dus in ons belang is het ook om zo min mogelijk fouten te maken. En dan kan de prijs ook goedkoper worden, want wij houden</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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|     |    | <p>nu ook rekening met faalkosten natuurlijk, in onze calculaties. Dus dat zijn ook dingen, dat we denken ja we kunnen natuurlijk die faalkosten [onverstaanbaar]. En die stukken die kun je ook opvragen, maar die faalkosten in de bouw, die zijn ook iets van 30% ofzo. Over de hele linie. Dus ja dat zijn geen, op een woonhuis waar nu de bouwkosten gemiddeld honderddertigduizend euro ongeveer liggen, dan praat je echt ver serieus geld. En dat is niet alleen bij ons, dat geld ook voor de stukadoor en voor de loodgieter, dat geldt voor de metselaar. Als die een stukje isolatie vergeet, wat ook wel eens gebeurt op dit moment. Nou dan is, die gebouwen die wij moeten verwarmen, nou dan moeten wij aantonen dat die de warmte niet haalt. Dan hebben wij zo'n warmtebeeldcamera en dan blijkt bijvoorbeeld de metselaar op bepaalde stukken de isolatie er niet in heeft zitten. Nou ja, dan moeten wij dat weer aantonen, dan moet de metselaar weer terug, een stuk metselwerk openhalen. Moeten wij weer terug om weer aan te tonen dat het nu wel goed is. Dat kost super veel tijd en geld.</p>                                                                                                                                                                                                                                                                                                                                                       |
|     | I  | Goed punt, ja, de faalkosten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 1Qb | I  | Nou je gaf van tevoren al aan, dat jullie als bedrijf zeg maar vanaf het begin betrokken zijn bij een project. En ik vraag me dan af op welke manier nemen jullie flexibiliteit mee in het ontwerpproces of het adviesproces?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P7 | <p>Normaliter wel. Wij proberen altijd onze installaties zo te maken dat, stel dat we al een fase voorbij zijn, hè, stel we hebben de ruwbouw en de afbouw fase vaak in het werk. Dan zeggen wij, wij nemen altijd al voorzieninkjes mee in de ruwbouwfase om te zorgen dat we in de afbouw fase niet tegen verrassingen aanlopen. Een voorbeeldje dat we hebben, als je bijvoorbeeld een rijtjeshuis hebt, dan heb je vaak, op zolder staat vaak de wasmachine of de wasdroger. Onze monteurs leggen standaard al extra leidingen naar de koker toe, die vaak in de hoek van de trap zit, om te zorgen dat we op zolder eigenlijk een paar pijpen extra hebben, mocht er een ontstopping zijn of mocht die klant in een laat stadium zeggen van goh ik wil toch mijn werkkamer op zolder maken en ik wil een datapunt of een wifipunt daar hebben of ik wil daar wel een extra slaapkamer maken. Dus wij zorgen dat we daar een extra groep leggen om verlichting aan te leggen bijvoorbeeld. Of een airco, bijvoorbeeld, dat is tegenwoordig natuurlijk heel erg in. En dat doen we eigenlijk ook naar de keuken. Standaard leggen we al twee loze leidingen naar de keuken, maar we hebben tegenwoordig een Quooker, we hebben een, je hoeft de boiler hoeft je niet meer te maken omdat je warmtepompen hebt, dus je hebt een Quooker, je hebt elektrisch koken, je hebt een oven, we hebben een vaatwasser. Nou tegenwoordig hebben veel mensen zelfs twee vaatwassers.</p> |
|     | I  | Ja?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | P7 | Ja! Volgens mij ben jij nog student.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | I  | Klopt, voor mij is dat geen realiteit.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P7 | Als je twee vaatwassers hebt, hoeft je geen bovenkastjes meer te doen. Want dan doe je in de een de vuile vaat en in de ander de schone.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I  | Echt? Is dat een ding?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P7 | Ja! Dan hoeft je het niet, dan ga je het uitruimen naar je kastje en dan pak je het weer als je gaat eten. Nu pak je gewoon je bordje weer uit de vaatwasser en de andere vul je weer met het vieze goed. Dus dat zie je steeds meer terugkomen. Dus wij maken echt wel veel huizen nu met dubbele vaatwassers bijvoorbeeld. Maar zeker als je allemaal druk bent, met sporten en kinderen, dan denk je nou we hebben allemaal gegeten nou ik zet het in de vaatwasser. De ander ochtend ga je ontbijten en dan haal je het bordje er weer uit en dan heb je je spullen weer. Dan hoeft je het niet in je kastje te doen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | O wat grappig.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P7 | <p>Dus dat zijn allemaal dingen, daarom leggen wij nu heel vaak ook naar de keuken vier vijf buizen alvast. Weet je, gebruiken we ze niet, dan kappen we ze af. Als we gaan afbouwen, dan beslissen we of we ze nodig hebben en dan kappen we ze bijvoorbeeld af. En die jongens die maken in dezelfde tijd eigenlijk dezelfde vloer. Dus echt dat kost ons niet meer. Wij hebben bij ons de afspraak dat ze gewoon twee vloeren, dus twee huizen verdiepingen, per dag maken. Nou dat is bij ons de stelregel. En we hebben jongens die doen dat in, die houden twee uur per dag over, en we hebben jongens die moeten tot 6 uur werken om dat voor elkaar te krijgen. Dus ja weet je wel, dat is een beetje de middenweg die we dan hebben. Dus we doen er nooit langer of korter over.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Maar het is voor jullie geen extra kosten om die extra leidingen aan te leggen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

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| 1Qc | P7 | Ja weet je, een buis kost 25 cent per meter, dus ja als we dan één keer moeten hakken, dan heb je die tien of vijftien euro buis dat heb je dan al terugverdient. Dus zijn bij ons al dingen om de faalkosten op te vangen eigenlijk. Plus, als wij het weer, stel dat dat huis verkocht is en die mensen die vinden het altijd prettig dat ze nog wat flexibiliteit hebben, dan kunnen wij eigenlijk de extra wensen duur verkopen met weinig middelen. Dus dat is ook vaak de truc die je dan toepast.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Klinkt logisch, inderdaad.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I  | Nou mijn volgende vraag is: wat zijn de huidige ontwikkelingen die je ziet op het gebied van flexibiliteit op jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P7 | Ja het stekkerbare, wat ik al zei. Wat we nu wel zien is, in de betonbouw, inkasting in de vloer. Dus dat stekkerbare zien we ook steeds meer in de gietbouw toegepast worden. Dus ik weet niet of je het systeem kent?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | I  | Nee, dat ken ik niet, nee.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P7 | Nee, als ik het onthoud kan ik je wel even een mailtje sturen anders. Dan voeg ik de documentatie ervan toe. Je krijgt nu al in de tunnelbouw wat flexibiliteit. Dat je wat stekkers op bepaalde plekken zet en dan kan je op het moment dat de vloer klaar is, dan trek je het naar beneden en dan klik je het er eigenlijk in. Dus dat plintgoten systeem van KISS begint weer een beetje terug te komen. Want je ziet nu ook bijvoorbeeld wanden, dat ze aan de onderkant er een vierkant uithouden waar je dan je leidingwerk kan verslepen. En dan later wordt dat dichtgezet en dicht gestukadoord bijvoorbeeld. Dus je ziet wel flexibele systemen ontstaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I  | En als je dat dicht stukadoort, kun je er daarna ook nog bij?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | P7 | Jawel. Dat kan wel omdat het een holle ruime is. Maar alleen wel de vakman vaak, hè. Want wij hebben dan, wij hebben hulpmiddelen om dingen op te zoeken. Wij hebben bijvoorbeeld, ja, een soort detector om te zien waar draden lopen. Dus wij kunnen dan bijvoorbeeld, als de plint dichtgesmeerd is, kunnen wij met een boor een gat boren en dan kunnen mensen met kleine handjes erin en die kunnen dan middels een veer daar naartoe en dan trekken we die eruit en dan leggen we er een extra kabel in en dan kunnen we stopcontacten bij maken. Dus die systemen die zien we nu wel ontstaan. Alleen we merken wel dat er nog steeds minder over nagedacht wordt door andere partijen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | En door andere partijen, bedoel je collega's in je vakgebied of andere branches?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P7 | Nee, niet. In de aannemerij, hè. Wij kunnen van alles verzinnen, maar als de klant er niet in mee wil, dan heb je een probleem. Kijk dat stekkerbare hebben wij heel erg voor moeten vechten om dat voor mekaar te krijgen. Want we hadden, vijf zes jaar geleden gingen wij een politiebureau verbouwen tot woningen, een oud politiebureau. En toen zei gewoon Eigen Huis, dat is gewoon wie de kopers begeleid, die zeggen ja dat willen wij niet hebben, want je bent niet flexibel, de klant kan niet de spullen kopen die erop aansluiten. Want normaal een stopcontact die kan je bij de Hornbach kopen en dan kan je het zelf doen. Maar onze ervaring leert dat er heel veel klanten juist niet zelf gaan rommelen aan elektrische installaties of aan loodgieterswerk. Want dat is een echt vak en gevaarlijk zelfs als je dat zou doen. Maar daar hebben we toen heel veel discussies over gehad en toen hebben wij het er op een gegeven moment doorheen gekregen door te zeggen van die stopcontacten die maken we flexibel. Want ja daar, heel vaak doet niemand daar wat mee. Alleen bijvoorbeeld voor naar de keuken, of de leidingen voor het internet, die maken we dan wel in een buis, dat dat later nog vervangen kan worden en verandert, dat je flexibel bent. Dus het komt ook vaak wel, het komt niet zozeer uit ons, wij willen wel, maar de bouwer, hè, die altijd vaak traditioneel is, of de opdrachtgever die traditioneel is, of de architect die heel erg traditioneel denkt. Die zegt, ja, dat doen we al twintig jaar zo, hoor je vaak bij ons. Dan denk ik ja, ja misschien ging het al twintig jaar verkeerd of had het sneller gekund. |
|     | I  | Ja precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P7 | Dat is zo'n mooi spreekwoord toch, van als je doet wat je deed dan krijg je wat je deed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | I  | Ja dat is waar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 1Qd | I  | In mijn onderzoek, zoals ik al aangaf, definieer ik flexibiliteit als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. Nou ben ik benieuwd wat voor jou een ingrijpende ingreep zou zijn, of wat nog geen ingrijpende ingreep zou zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

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|  | <b>P7</b> | Ja, een ingrijpende ingreep is bijvoorbeeld als je de badkamer of de keuken naar een hele andere plek in het huis brengt. Dan ben je echt natuurlijk op slopershoogte. Een afvoer van een wc, die heeft een, dat noemen ze afschot bijvoorbeeld, een afvoerbuis moet per meter een centimeter schuin aflopen. Dus als je die natuurlijk van de ene hoek naar de andere in een huis gaat verplaatsen, ja dan kan dat misschien niet meer en zitten er te veel bochten in, dus ja. Het wordt helemaal gemaakt bijvoorbeeld, dat als er bijvoorbeeld bovenin doorgetrokken wordt, dat het helemaal naar beneden loopt, naar beneden valt, naar de straat toe loopt. Zelfs van het huis naar de straat, zit die centimeter per meter erin. Daarom liggen die riolen ook altijd laag in de straat. Dus daar kan je heel weinig mee. Dat geldt bijvoorbeeld voor waterleidingen ook. Als je bijvoorbeeld, als je waterleidingen wil gaan verslepen in de woning. En er ligt bijvoorbeeld vloerverwarming, wat heel vaak gebeurt. Een waterleiding, bijvoorbeeld een koud waterleiding, mag niet tussen de verwarming liggen. In verband met legionella. Dus ja dan ben je heel erg beperkt in verplaatsen en ingrijpende verplaatsingen. Dus dat geldt dus voor de keuken en de badkamer. Kijk, lichtpunten en stopcontacten kan je redelijk verplaatsen, ook in beton. Dan moet je echt gaan slijpen in vloeren. Maar alles wat door de vloer heen gaat, kan je ook niet doen, omdat er vloerverwarming ligt. Dat slijp je dan helemaal kapot bijvoorbeeld. Dus ja weet je wel, dus je bent echt als je wanden gaat verplaatsen enzo, ben je echt op slopershoogte. Of je moet een ruimte creëren tussen het plafond en de vloer in. Wat ik zei, een beetje zo'n holle ruimte waarin je wel heel makkelijk wat kan verslepen. Met een soort kruipluiken erin, of luiken erin op bepaalde plekken. Ja dan kan je wel wat doen. |
|  | <b>I</b>  | En dan bij voorkeur aan de onderkant omdat aan de bovenkant de vloerverwarming ligt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|  | <b>P7</b> | Ja, ja bijvoorbeeld. Maar ja, je kan bijvoorbeeld een technische ruimte om bij een, aan de zijkant van een trap bijvoorbeeld, hè. Als je een trap omhoogloopt, heb je natuurlijk altijd een vloer, dat wordt afgetimmerd. Nou daar zou je bijvoorbeeld een luikje in kunnen maken, waar je bijvoorbeeld met je handen bij kan. Je zou bijvoorbeeld, onder de douchehoek, als je die niet tegelt, maar zo'n standaard douchehek koopt, dan kan je natuurlijk zorgen dat die verplaatsbaar of vervangbaar is bijvoorbeeld. Dus er zijn best wel oplossingen voor, maar ja, in beginsel om dat te leren en dat aan te leggen, kost het meer dan als je het in de basis, in de standaard doet. Er zijn wel standaardartikelen en standaardmethodes, alleen als je flexibel naar de toekomst toe, dan kost het in beginsel gewoon altijd meer om het uit te vinden, alleen naar de toekomst toe ben je flexibeler. Alleen, ja de vraag is waarom zou je de keuken willen verplaatsen? Waarom zou je de badkamer willen verplaatsen. Wij doen heel veel huizen, tweënhalfduizend huizen per jaar, nou en om de badkamer en de keuken te verplaatsen, ja dat gebeurt bijna nooit. Het enigste wanneer wij dat hebben is in hele dure grachtenpanden in Amsterdam bijvoorbeeld, van miljoenen, dan heb je natuurlijk mensen, ja die vinden nooit iets leuk en krijgen hun geld niet op, dus die zeggen doen hem maar van de ene naar de andere kant. Dus dat. Of grote renovaties. Maar over het algemeen in een nieuwbouwwoning gebeurt dat niet zo vaak. Dus, dan zou het om grote aanpassingen, dat zouden wandenverplaatsingen zijn.                                                                                                                                                                                                                                                                                         |
|  | <b>I</b>  | En als ik het goed begrijp, wat hem dan ingrijpend of lastig maakt is de manier waarop dat systeem dan met de rest van de systemen geïntegreerd is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|  | <b>P7</b> | Hoe dat aankoppelt ja. Wij berekenen veel installaties. Dat geldt dan voor elektra wat minder als bij verwarming, maar bij verwarming, water, afvoer, die worden berekend. Op een bepaald iets, en die berekeningen geven aan dat die buizen een bepaalde dikte moeten hebben of een bepaalde, naja, afschot moet hebben, of een bepaalde druk moet hebben. En als je dat nu gaat aanpassen, dan zullen al die berekeningen opnieuw gedaan moeten worden en dan zal bijvoorbeeld, je kan niet zeggen, want als je bijvoorbeeld iets overmaats maakt, ja dan heb je kans dat er weer herrie ontstaat. Bijvoorbeeld bij de wc doortrekken, als die te groot wordt, dan komt er weer een te groot volume en dan hoor je dat door die hele woning. Dus er zitten allemaal do en don't aan vast.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|  | <b>I</b>  | Een heel kader, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|  | <b>P7</b> | En als je weer zo'n flexibele vloer hebt, waar je weer alles in doet. Ja dan zou je die weer beter moeten isoleren bijvoorbeeld.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|  | <b>I</b>  | Vanwege het geluid?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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|                                       | P7 | Wat wij altijd hebben met een project. Vroeger had je natuurlijk iets heel simpels, je had een CV-ketel, je had elektra. Tegenwoordig heb je zoveel knoppen waar je aan kan draaien, zeggen we maar. Dat en een stukje wetgeving. En er zijn gewoon heel veel wegen die naar Rome leiden. Dus je moet op een gegeven moment ook weten aan welke knoppen je moet draaien. Aan welke knop draai je? Wat is dan het beste resultaat?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | I  | Op basis van ervaring?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                       | P7 | Ja op basis van ervaring, maar ook op berekening. Als de berekening zegt ja we zullen toch iets meer moeten verwarmen dan koelen, even als voorbeeld, dan moeten we ook bijvoorbeeld de slangen van de vloerverwarming dicht bij elkaar leggen. Omdat we meer koelvermogen hebben als dan verwarmingsvermogen. Dat zijn allemaal dingetjes, waar je later pas over beslist. Net als bijvoorbeeld een bad. Als mensen een bad nemen, dan moeten wij daar eigenlijk een boiler voor neerzetten. Dus als wij, bij een standaardhuis zit er standaard geen bad. Dus wij moeten signaleren, op het moment dat er een bad komt, dus uit een meerwerk lijst, bij de keukenboer, bij de badkamerman geweest en die bestellen een bad zonder ergens over na te denken. Dan moeten wij signaleren van hup er komt een bad. Want dat betekent dat ik meer boilerinhoud moet hebben, want een normale warmtepomp op dit moment doet het drie uur voordat dat bad gevuld is. Ja. Dus ja, dan moeten wij aanpassingen gaan doen aan een installatie.                                                                                                                |
|                                       | I  | En dat is dan ook een nieuwe ontwikkeling sinds die warmtepomp een ding geworden is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P7 | Ja, die heeft gewoon veel minder kracht dan een gasleiding. Dus ja weet je wel, alles wat je doet heeft een bepaalde impact. Dus jij koopt bijvoorbeeld een leuk huis en je wil er een bad in hebben en er staat een warmtepomp. Dan zeg je goh ik bel Pietje, die ik ken en die maakt er maar een bad in. En ja dan ga je een bad vullen en er gebeurt niets. Want, laten we zeggen, een bad is gemiddeld driehonderdveertig liter. Na honderd liter krijg je koud water. Ja dus, dat is allemaal, daar zitten allemaal gemenigheidsjes in. Dus dat is een beetje ons vak, dat je echt wel na moet denken. Dus als je flexibel wilt zijn, ja zou ik echt naar holle vloeren gaan. Of dat je de oplossing overmaats situeert, dat je alles groter uitvoert. Maar dan, ja, heb je kans dat je heel veel dingen niet gebruikt. Ik noem Tesla nu als voorbeeld. Elke auto, de duurste en de goedkoopste hebben dezelfde boardcomputer. Dus ja, die doen bijvoorbeeld overmaats die boardcomputer erin zetten. En dan ja, maar dat betekent wel dat ie wel makkelijker bouwt nu. Nu is elk project uniek, dus dat is weer het nadeel van al die systemen. |
|                                       | I  | En als je dat meer zou standaardiseren, zou dat makkelijker gaan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | P7 | Makkelijker en misschien goedkoper worden ook. Want dan maken we de voorbereidingen voor dat bad al bij iedereen bijvoorbeeld. Ja dat betekent wel dat je de initiële investering hoger legt. Ja als we ook een dop in de vloer moeten maken als afvoer. Ja die kan weer gaan stinken als die niet gebruikt wordt. Maar goed. Weet je wel, het heeft allemaal met elkaar en consequenties te maken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                       | I  | Het is één groot spinnenweb.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                       | P7 | Ja, één groot spinnenweb.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 2Qa                                   | I  | Mijn tweede topic, dan gaan we echt in op vloeren, nou gaat het al een tijdje een beetje over vloeren. Mijn eerste vraag is een hele algemene vraag. Wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                       | P7 | Ja, de vloer waar ik op sta, is de vloer. En omdat ik natuurlijk een installatietechnicus ben, is de vloer ook waar ik naar toe kijk, boven me. Dus zo moet je het even zien. Dus de vloer is waar ik mijn leidingen in aanbreng.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | I  | En je brengt die eigenlijk altijd alleen maar aan in de vloer, of zijn er ook nog...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                                       | P7 | Ja of tegen de vloer, in de vloer, of op de vloer. Zo wordt dat bij ons gezegd, hè. Dat is net het bouwsysteem dat je kiest. Van ja boor het maar tegen de vloer aan, dat is utiliteit hè. En bij woningbouw, maak het maar in de vloer. En als we het in een smeervloer maken, zeggen we maak het maar op de vloer, weet je wel. Dat zijn de krenten die we hanteren dan. Dat weten wij uit onze ervaring, als we dat tegen een monteur zeggen of tegen een projectleider, ja dan weet hij precies wat ik bedoel. Bij ons wordt ook van tevoren altijd gezegd, als wij een begroting maken of bij projectoverdrachten, dan geven wij altijd wel aan de monteur dit bouwsysteem wordt gehanteerd. Daar beginnen we altijd mee. Het project ligt daar en daar, dit is de opdrachtgever en dit is het bouwsysteem dat gehanteerd wordt. Dan weet hij hoe die het moet gaan maken.                                                                                                                                                                                                                                                                       |



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|     | I  | Je geeft aan dat de vloer hetgeen is waarin, op, of rond de installaties komen. Waarom zitten de installaties altijd in de vloer?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P7 | Ja omdat, ten eerste bijvoorbeeld, de verwarming zit in de vloer omdat die het hele parket moet opwarmen. Anders heb je natuurlijk echt koude voeten. Dus daarom is die vloerverwarming natuurlijk heel lekker, hè. Want dat is natuurlijk een geleidelijke warmte. Maar hij warmt ook het hele huis, het warmt het hele beton op. Ja ik kan het wel tegen de muur aan zetten. Ja vroeger deden we dat ook, dan hadden we een knuffelmuur. Weet je wel, in zwembaden heb je dat nog wel eens. Ja doet het niet zo lekker als in de vloer eigenlijk. En plus, de vloer wordt min mogelijk geboord, hè, want daar zet je je bankstel neer. In de wanden, wil je schilderijtjes ophangen, een wandlampje, een speaker. Weet je wel, dat soort dingen. Een plankje. Dus we proberen die wanden zo vrij mogelijk te houden. Ja en waterleidingen, alles, in het zich, is natuurlijk niet fraai. Bij bijvoorbeeld utiliteitspanden is het wel eens in zicht maar dan. Kijk we hebben allemaal kreten, hè. Dan noemen we het speels. Als iets een zootje is noem ik het speels. Als je overal leidingen kriskras hebt lopen. Dat klinkt liever dan als ik zeg het is een zootje. En als het, bijvoorbeeld in een betonnen kolom, dan zeg je ja het is een industrial look. Een industriële look, ja dan mag het in het zicht. Bij huizen, ja, in standaard rijtjeshuizen, ja dan willen mensen het niet in het zicht. Ja die zijn gewend natuurlijk, stukadoors en noem maar op. Ja het is soms ook niet praktisch. Want bijvoorbeeld een waterleiding moet je isoleren dan. Als je die in de vloer legt is die al deels geïsoleerd. Als ik hem moet isoleren, nou dan is het van dat hele vieze piepschuim wat eromheen komt. Ja daar kan een kind weer aan zitten. Een leiding voor een verwarming, van vroeger die verwarming, die worden weer heet, dat is weer gevaarlijk voor kleine kinderen. Weet je wel, dat soort dingen. Dus het liefst werken we alles weg om het netjes te maken. Ja vroeger. En vroeger, laten we zeggen in de oorlogsjaren, zijn er heel veel installaties gemaakt, allemaal in het zicht. Ik kom nog wel eens in gebouwen met een wc en dan zie je alle waterleidingen nog lopen bijvoorbeeld. Dat doen we nog wel eens meer. Dat vinden mensen soms ook praktisch, maar ja de architecten vinden het weer niet mooi, hè. Dus ja zoveel mogelijk wegwerken. |
|     | I  | Esthetisch ook een groot deel?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P7 | Ja. Esthetisch is ook echt wel een dingetje. Ik zeg altijd, elke generatie heeft zijn eisen. Ik merk gewoon heel erg dat de generatie, waarschijnlijk jouw generatie, minder eisen stelt aan het behangetje en het granolletje, dan mijn generatie of mijn ouders' generatie. Ik zeg altijd, die generatie hierna, die gamen, die zetten de VR bril op hun hoofd en die gaan in hun eigen virtuele wereld zitten. Dan mag alles wit zijn, die zetten een zitzak op de grond en die hebben het voor mekaar, weet je wel. Dus ja, elke generatie heeft ook eigen eisen en wensen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I  | Dat sluit wel goed aan op mijn volgende vraag, want dat is: welke trends zie je in de ontwikkeling in jouw vakgebied, die invloed kunnen hebben op het ontwerp van vloersystemen? Nou dat hoeft dus niet persé flexibiliteit te zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 2Qc | P7 | We zien wel, deels minder mogelijkheden, maar ook bijvoorbeeld we zien natuurlijk heel erg, vroeger moest je natuurlijk de voorzieningen voor de televisie en internet, maar tegenwoordig wordt natuurlijk alles Wifi. Dus dat merk je eigenlijk heel erg, hè. Sommige dingen worden minder en sommige dingen worden meer. Ja en de trends die er zit, is natuurlijk vaak dat het uit de fabriek wordt. Dus eigenlijk wat Van Wijnen heeft met dat Fijn Wonen. Dat zie je natuurlijk wel steeds meer. Dat de werkzaamheden van de bouwplaats verschoven worden naar de fabriek. Dat vergt van ons, wij koppelen dan bijvoorbeeld op de bouw, noemen we dat. Wat je ook wel vaak ziet, is dat alleen de wanden in de fabriek gemaakt worden en dat een deel van de vloeren en dat wij wel alles in de vloeren aan elkaar koppelen. Dat is een slim systeem, maar dat betekent wel dat we aan de voorkant, dus normaal waar we werk op de vloer zouden hebben, met het meten, dat doen we nu in een 3D systeem aan de voorkant bijvoorbeeld. Wij tekenen alles in 3D, dan kan de fabriek uit dat driedimensionale model, kan die alles weghalen. Wat wel vergt dat het heel goed op mekaar moet aansluiten. Er moet bijvoorbeeld geen radiator voor de stopcontacten zitten. Of de afvoeren moeten niet, die lopen dan opeens voor een buitenlichtpunt langs. Dat soort dingen zien we nog wel veel gebeuren op dit moment. En omdat je vaak merkt dat degene in de fabriek niet het verstand heeft van de praktijk. En bij ons is echt, als wij iets tekenen, dan zit er een tekenaar, nou dat kunnen best hele jonge mensen zijn, hè, dat is natuurlijk heel hip met die 3D modellen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |



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|                                              |    | enzo. Maar er zit vaak een ouder iemand naast om mee te kijken, voor een bepaald gedeelte van joh kan dat wel in de praktijk. De computer kan berekenen dat ik er vierentwintig bochten in maak, maar dan zegt die oude rot die zegt dan ja dat doen we zo niet, dat werkt gewoon niet, waarom doen we het niet zo, weet je wel. En daar leren we dan weer van met mekaar. Je ziet wel een beetje die trend naar het bouwen in de fabriek gaan. Dat zal niet altijd zo worden. Want wij merken ook wel dat maatwerk, mensen met geld, wij hebben dan ook een soort kopers begeleiding intern bij ons, nou wij krijgen toch 250 gezinnen op bezoek, die echt met ons de woning helemaal doorlopen van begin tot eind. En die willen echt kun lichtpuntjes boven die keukentafel hebben, die willen hele trendy spots hebben, die willen hun tv's aan muren, een jacuzzi in de tuin, of jacuzzi in het bouwgebouw. Nou dat zijn natuurlijk leuke dingen. Of hele, hoe noemen ze dat, man caves maken. Nou dat gaan we natuurlijk niet standaardiseren natuurlijk. |
|                                              | I  | En dat heeft effect op je ontwerp in de zin dat je andere installaties moet verwerken, of meer installaties?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                              | P7 | Ja, maar dat kiezen we ook vaak samen met de aannemer en opdrachtgever. Dat we een flexibel systeem hebben, omdat er zoveel in komt. Wat we van tevoren bijna niet kunnen vangen. Dus even zo'n voorbeeld van een man cave. Dan heb je vaak een beamer, daar zit een hdmi kabel aan die heel dik is, daar zitten led strips, er zitten speakers ingestort in het plafond. Nou vaak nog kleuren leds en ledjes bijvoorbeeld. Ja, een tapinstallatie. Ja, de gekste dingen. We hebben ook wel eens een soort zwembad, wellness ding gehad. Dus ja weet je wel, dat zijn best leuke dingen om te maken. Maar dat kan je niet in een vast bouwsysteem vangen. Maar dat zal ook altijd zo blijven, hè. Dat zijn de mensen met de centen, in de nichemarkt. Die zeggen joh is wil niet die eenheidsworst zijn. Die willen pronken met wat ze hebbe, hè. We zijn nu een heel groot huis voor iemand aan het doen. Nou je merkt echt dat die het doet voor de buurt en niet voor zichzelf. Die hebbe we er ook bij.                                                     |
|                                              | I  | En als je het hebt over die prefab van hiervoor. Dat verandert dus jouw proces, doordat je het van tevoren allemaal moet intekenen in een 3D model. Dat is de verandering die het meebrengt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                              | P7 | Ja. Het proces verandert. Ik moet er van tevoren over nadenken, of alles moet van tevoren bekend zijn, voordat we gaan starten. Nou werkt daar de wet kwaliteitsborging ook in mee. Want die gaat steeds meer eisen, dat vier weken voor aanvang van de bouw dingen ook echt getackeld zijn. Ja dus je moet echt dingen vastleggen. En voor ons van invloed, zonnepanelen bijvoorbeeld. Het aantal zonnepanelen is van invloed aan de voorkant, hoe je dingen gaat aansluiten en uitvoeren, hoe de meterkast in mekaar zit. Dus ja het liefs, je ziet steeds meer dat, vroeger zeiden ze dat los je op de bouw maar op. Dat los nu eigenlijk aan de voorkant heel vaak al op. Wil niet zeggen dat het altijd beter is hoor.                                                                                                                                                                                                                                                                                                                                     |
|                                              | I  | Nee?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                              | P7 | Nee, op de bouw worden er nog veel fouten gemaakt, hoor. Soms komt het op de bouw aan en dan is het beschadigd en dan is het, dus het is echt heel de keten waar je mee te maken hebt dan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Topic 3: Opportunities and challenges</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>3Qa</b>                                   | I  | Oké, nou dan wil ik naar mijn derde en laatste topic gaan. Welke kansen zie je voor flexibiliteit met betrekking tot jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                              | P7 | Ja, de kansen heb ik eigenlijk al genoemd. Als we standaardiseren, kan ik sneller werken, kan ik meer installeren. Dat zijn eigenlijk de kansen die ik daarvoor zie. Standaardiseren en dat ik dus eigenlijk, de kansen die ik eigenlijk zie is dat ik ook deeltaken, mijn mensen zijn nu eigenlijk heel allround, hè, die maken alles. En je kan nu ook bijvoorbeeld, door het flexibiliseren, kan je zeggen van joh ik heb zo meteen alleen maar mensen die dingen aan mekaar klikken of die bijvoorbeeld alleen maar stopcontacten aan mekaar klikken. Dus je kan ook je werk nu zo meteen in partjes standaardiseren. Dat is onderdeel ervan. Plus als je die flexibiliteit, die standaardiseren maakt, dan kun je ook zeggen ik kan heel makkelijk van tevoren uitmeten en netjes in doosjes doen, katten noemen we dat, dus je kan ook dingen veel beter klaarzetten voor de monteur. Dus je kan eigenlijk die logistieke stroom veel beter beheersen.                                                                                                    |
|                                              | I  | En zijn de faalkosten daar ook nog een onderdeel bij?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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|            | <b>P7</b> | Ja, dat zou betekenen dat ik minder faalkosten zou hebben. Dat is natuurlijk slecht van tevoren in te schatten, maar ik schat in dat als iemand elke dag in dag uit hetzelfde doet. Ik moet er niet aan denken moet ik eerlijk zeggen. Maar er zijn mensen, die vinden dat heel prettig, die werken nu ook in een fabriek of die komen uit een Oostblokland, die zijn niet beter gewend. Ja, ik heb altijd geleerd dat als je iets heel vaak doet, dat je er beter in wordt. Ja dat is een beetje het, als iemand dat doet, dan gaat hij het steeds sneller en beter doen en dan ziet hij ook vaker de fouten, dus dan maak je minder fouten. Dus ik zie in de toekomst daar echt wel minder fouten uit komen en de faalkosten naar beneden gaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>3Qb</b> | <b>I</b>  | Nou, dan de andere kant van datzelfde muntje. Welke uitdagingen of obstakels voorzie je voor flexibiliteit in je vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|            | <b>P7</b> | Ja toch de vakmensen nog steeds weer. Toch de mensen met verstand, die echt moeten weten hoe het zit. En ook wel dat andere partijen zich gaan mengen in installaties. Wij, hè, wij waren nu gewend, je was echt de vakman en je was op je vakkennis geselecteerd. Maar we zien in de toekomst meer dat het een bedreiging vormt dat ook andere partijen, bijvoorbeeld een Ikea, die is ook bezig om een flexibele woning te maken, of andere partijen. Ja die gaan buiten ons om of die maken het in een ander land. Ik weet, een vriend van mij, die importeert spullen uit China en die zegt joh ik heb een architect, die haalt gewoon complete huizen uit China vandaan. Die komen dan aan, die voldoen niet aan onze maatstaven, maar die hoeven maar hele kleine dingen aan te gebeuren en dan voldoet het wel. Ja daar komen wij niet eens aan te pas. Want ik heb die man wel eens gebeld. Toen zei ik joh kunnen wij nog wat voor je betekenen. Hij zei nee joh het is eigenlijk gewoon lego. We krijgen echt een bouwplaat hiero en we doen het allemaal aan mekaar en dan komt er af en toe eens een ventje kijken van gaat het goed en dan houdt het op weet je wel. Dus ook die flexibele systemen, dat kan ook nog een nadeel voor ons zijn. En nou ben ik er niet zo heel bang voor. Kijk wij hebben honderd vakmensen en vakmensen zijn onbetaalbaar, die zullen altijd blijven, ook voor bestaande huizen en zaken. Maar in de nieuwbouw, is het denk ik echt wel een bedreiging.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|            | <b>I</b>  | Ja dat kan ik me voorstellen, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|            | <b>P7</b> | Snel mijn bedrijf verkopen! Nee dat is gekheid. Maar je ziet wel of ik moet mee of je moet zeggen ik stop ermee. Dat merk ik wel in heel veel dingen. Wij proberen als bedrijf toch mee te gaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|            | <b>I</b>  | En wat is daarin jullie speerpunt, in het daarin meegaan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|            | <b>P7</b> | Heel dicht tegen de klant aanhangen met hun meedenken. En ook wat ik zeg, blijven kijken naar de nieuwe technieken. Wij schrikken niet als er een nieuwe techniek op de markt komt, omdat wij hem eigenlijk al gezien hebben. Dat betekent heel veel lezen. Wij hebben een soort, ja, commerciële voorhoede noemen we dat in het bedrijf, die lezen allemaal heel veel en die houden de vakbladen bij. Dus als we iets nieuws zien, dan delen we het met mekaar. En dan gaan we er tijd voor maken om te kijken, hè, van is het wat voor ons om in te zetten, of is het een bedreiging, of is het een kans? Dus ja, zo houden we ons, als bedrijf, houden we ons actueel. Dus zo zitten we altijd net, ik hoef niet helemaal voorop te lopen in de markt, hè, want als je helemaal vooroploopt dan is het maar eenzaam. Maar wel zorgen dat we net een stapjes voor zijn op onze conculega's of concurrenten. Dat proberen wij elke keer wel te doen. Wij zijn nu bijvoorbeeld met batterij technologie bezig voor de zonnepanelen. Nou dat is nu nog niet heel erg gebruikelijk. Alleen wij doen nu wel alvast de eerste systemen draaien, gewoon om van te leren. Verdienen we heel weinig geld mee, of geen geld mee. Alleen als wij die kennis in vraag hebben en een klant die vraag stelt, dan heb ik het al een keer gemaakt, dan weet ik hoe. Wij denken dat die trend, over één of twee jaar, heel snel, overal komt. Stukje energieopslag. Dat zijn dingen waar wij naar voren kijken. Bijvoorbeeld de laadpalen, zijn we nu bijvoorbeeld ook mee bezig. Om te kijken hoe we dat naar voren kunnen trekken. We kijken echt wel naar een stukje flexibel, in partjes hakken van de stukjes installatiewerk. Een stuk standaardisatie. Merkkeuzes maken. Dus niet elke keer mee gaan met de klant van goh ik vind merk X leuk en merk Y. Nee joh, wij doen alles met merk X want dat hebben we op de plank liggen, we weten hoe het werkt, we hebben er een service apparaat voor. Dus ja kies je voor ons, soms moet je dan heel stoer zeggen dat je niet met merk Y wil werken. Maar het geeft ook heel veel rust binnen je organisatie. |

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|  | I  | Maar dan weet je ook later welk product je gebruikt hebt, mocht je er nog iets mee moeten?                                                                                                                                                                                                                                                                                                                             |
|  | P7 | Wij standaardiseren ook heel veel in onze groepindelingen. De wasmachine, bijvoorbeeld, zit altijd op dezelfde stop bij elk huis dat we doen. Nou ja we doen tweeënhalfduizend huizen. Dus als de wasmachine eruit ligt, dan is het van mij zo hé groep 5 ligt eruit, loop eens naar de meterkast, kijk eens naar nummertje 5, o die staat naar beneden, o de wasmachine, nou zo. Dus die standaardisatie doen we ook. |

Table B.11: Transcription interview P8

|                                          |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                        |
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| <b>Interviewee</b>                       |    | P8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Architect at a small architecture firm |
| <b>Date and time</b>                     |    | April 20 <sup>th</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 9:00                                   |
| <b>Topic 1: Flexibility of buildings</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                        |
| Q1a                                      | I  | Kun je mij vertellen over de huidige staat van flexibiliteit binnen jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                        |
|                                          | P8 | Ja. Eigenlijk is die relatief klein, die vraag. Maar dat heeft ook te maken met dat ik met name in de woningbouwsector werkzaam ben. Als je je met kantoren enzo bezighoudt, dat is altijd al dat dat veel flexibeler is. Ja, als je kantoren bouwt dan maak je eigen alleen maar lege hulzen waar van alles in kan. Wij zijn natuurlijk met woningen bezig en dat is veel bepaalder. En op het moment als je die flexibiliteit daarin wil brengen, dan zit dat vooral in hoe ga je zorgen dat iets levensloopbestendig is. Het komt er eigenlijk gewoon op neer dat je het dan groter maakt. En dus stel een persoon komt op een gegeven moment in een rolstoel of wat dan ook, ja dan moet die goed vrij kunnen bewegen in die woning, moet die overal draaicirkels hebben, moet de slaapkamer iets breder zijn, moet de trap een bepaalde afmeting hebben. Ja die moet sowieso afmetingen hebben, maar als je trap maakt met een krul daar in het bovenpart dan is het weer lastig om een traplift te maken. Dus eigenlijk op dat niveau is vooral die flexibiliteit die dan speelt bij ons. Wij zijn op dit moment ook bezig met een plan waarbij we ook meer circulair aan het denken zijn, of dat nog aan het uitzoeken zijn wat dat dan zou betekenen. Als een gebouw, een gebouw voor studenten woningen, hier in [middelgrote Nederlandse stad]. Op het moment dat je dat helemaal circulair wil ontwerpen, dan werken we eigenlijk twee varianten uit. Of eentje gewoon in beton, traditioneel, in het werk gestort, gemetselde gevels. Of een variant waarbij de constructie helemaal is staal is met kanaalplaatvloeren en houten scheidingswanden, zodat je dat op termijn kunt demonteren en dat je het helemaal circulair kunt gebruiken. Ja ik zelf denk altijd als je iets duurzaam wil maken, moet je gewoon vooral zorgen dat het heel lang mee kan. Kijk wij zitten zelf in een pand uit 1578, kijk ja dat is natuurlijk heel duurzaam! Dat is allemaal natuurlijk gemetseld, het is niet hightech hoe het gebouwd is. Maar het is wel heel duurzaam omdat het gewoon eeuwenlang mee kan. Dus dat is misschien nog wel duurzamer dan dat je iets maakt wat je weer uit elkaar wil halen. Dus dat is altijd een beetje zoeken. In ons werk proberen we altijd, ook als we woningen ontwerpen, om die woningen zo, ja, om zoveel mogelijk gebruiksmogelijkheden te creëren in die woning. Om niet te definiëren dit is persé de enige plek voor de keuken of dit is de enige plek om een eettafel neer te zetten. |                                        |
|                                          | I  | En hoe doe je dat? Dat creëren van bredere gebruiksmogelijkheden?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                        |
|                                          | P8 | Nou wat we bijvoorbeeld wel eens doen als je een woning hebt of een appartement aan een galerij, nou dan kun je bijvoorbeeld de slaapkamers aan de galerij leggen en de woonkamer en de keuken aan de andere kant, waar je het balkon hebt, meer de privé kant. Wij proberen dan vaak de woonkamer juist helemaal in de diepte van de woning te leggen, dus dat die woonkamer ook nog aan de galerij grenst. Nou ten eerste is dat mooi voor het beeld. Want dan heb je niet alleen maar vitrages van slaapkamers aan de galerij en je hebt gewoon de levendigheid van dat er ergens gewoond wordt, dus dan heb je een deel van die woonkamer die daaraan grenst. En daar zit dan bijvoorbeeld die flexibiliteit in dat je een deel van de woonkamer, wat aan die galerij grenst, dat je daar ook weer een aparte slaapkamer van kan maken. Dus je ontwerpt dan iets als een driekamerwoning bijvoorbeeld, maar je kunt er met een heel simpel wandje een vierkamerwoning van maken. Dan wordt je woonkamer natuurlijk kleiner, maar dat is natuurlijk logisch. Het liefst maak je alles heel groot maar je staat natuurlijk altijd nog op gespannen voet met de bouwkosten. En dat is eigenlijk ook wat ik net vertelde over die studentenhuysvestingen. Daar zijn we nu aan het onderzoeken, maken we het in staal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                        |

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|     |    | met kanaalplaten helemaal circulair, of doen we het traditioneel? En dan blijkt gewoon meteen al, ja dat circulaire verhaal dat is 60 tot 70 procent duurder.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | 60 tot 70 procent?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P8 | Ja, althans dat zijn nu even de eerste conclusies, hoor. Maar het is dus echt, ja, dan is gelijk de vraag ja wat heb je ervoor over?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | I  | Ja dat is wel een hele boel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P8 | Ja dat is wel een hele boel! De opdrachtgever zegt zo meteen nou laat maar zitten. Nou misschien is het 55 of 65 hoor, maar het is wel echt, echt gigantisch veel duurder. Althans, we zijn met een schetsontwerp bezig, dus het is in een heel vroeg stadium. Maar de eerste verkenningen wijzen dan wel uit van dat is duurder. Ik denk dat heeft ook te maken met dat de bouw daar volgens mij nog niet heel er in mee gegaan is. Ja alles wat anders is dan hoe je dat altijd doet, dat is natuurlijk logisch dat dat duurder is. Dat klinkt een beetje stom. Maar het is anders en anders betekent risico's. Ja dan moet dan natuurlijk afgedekt worden met geld. Dus dat is een beetje het lastige. Dat je dan merkt van iedereen wil dan wel, maar het is heel snel van ja wie gaat dat dan betalen. Maar dat is dan een studentenhuysvesting en dat is dan ook een gebouw wat helemaal met een kolommen structuur ontworpen is, vooralsnog. Wel ook met het idee, of je het nou van beton maakt of van staal, als je een kolommenstructuur hebt dan kun je daar op termijn ook een kantoor in maken, of wat dan ook, of grotere woningen. Zo is dat dan bedacht. Maar dat is best uitzonderlijk in ons werk, dat we op die manier daaraan werken. Verder is die woningbouw wel redelijk traditioneel moet ik zeggen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q1b | I  | Mijn volgende vraag heb je het wel al een beetje over gehad. Ik ga hem toch nog even stellen om te kijken of er nog iets anders omhoogkomt. Op welke manier neem je zelf flexibiliteit mee in je ontwerpproces?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P8 | Ja dat is eigenlijk wat ik net zei. Wij vinden het gewoon belangrijk dat als je een woning maakt, ik zeg ook wel eens tegen mijn collega's we hebben eigenlijk ook een soort maatschappelijke taak! We zijn niet alleen maar aan het bouwen en geld verdienen met huizen, waar we willen ook gewoon goeie woningbouw maken, die mooi in de context is, en die goed gebruikt wordt, maar die ook mooi blijft, dus die er ook over dertig jaar nog goed uit ziet, mooi verouderd. Dus zo proberen we altijd wel ook in die plattegronden die we daarbij ontwerpen, zoals ik inderdaad ook al als voorbeeld gaf, die flexibiliteit aan te brengen. Dat het niet alleen maar door een student bewoond kan worden, of alleen maar door een ouder iemand. Alleen is dat vaak ook wel een soort flexibiliteit in het ontwerp, dus dat je het in het ontwerp heel makkelijk kan veranderen, maar dat is vaak ook wel iets anders dan flexibiliteit in werkelijkheid, in het gebruik. Dat betekent dat je zegt goh je kunt heel eenvoudig dit wandje weg, dat wandje weg, badkamerwand een stukje opschuiven, nou heel flexibel ontwerp. Maar als het eenmaal gemaakt is in één van die varianten, dan is het heel ingrijpend als je een badkamerwand moet verplaatsen. Want dan moet het leidingwerk moet eruit en het leidingwerk zit in de vloer erboven, dus dan ben je echt, terwijl je denkt o ik schuif even het wandje 20 cm op, dan is dat in praktijk heel ingrijpend. Dus dan lijkt iets heel flexibel omdat het in het ontwerp heel flexibel is, maar in de praktijk is het toch niet heel erg flexibel want dan moet daar gigantisch veel geld in gestopt worden om een relatief kleine wijziging aan te brengen. Dus dat is misschien wel leuk voor jouw onderzoek, om te kijken hoe je daarop voorbereid kunt zijn. Dat je bijvoorbeeld, veelal komen de leidingen uit de vloer boven de ruimtes naar beneden in de wanden en die worden dan ingefreesd. Dat is trouwens ook iets heel traditioneels, dan wordt eerst die hele wand gemaakt en dan wordt die halve wand wegge-, dan denk je ook eigenlijk wat is dit voor gekkigheid, maar goed. En die punten waar de leidingen uit de vloer komen, die staan natuurlijk precies vast, want die moeten precies op het hart van waar die wand komt naar beneden komen. Dus dat is zeg maar misschien voor jou of jouw onderzoek misschien wel heel interessant. Hoe kun je zorgen dat op termijn, dat je dat al voorbereid in die vloer, dat je die leiding ook 30 cm verder, of 10 of 15 cm verder naar beneden kan laten komen. En hoe je dat dan op termijn nog mogelijk maakt. Daar kan ik me wel iets bij voorstellen. Dat is misschien ook meer een verhaal voor installateurs? Maar dat is wel waar wij tegenaan lopen. |
|     | I  | Ja, wat ik voor mezelf een beetje voor me zie is dat ik het 'hulsel' waarin de installateurs hun ding kunnen doen dan ontwerp. Maar daar hoort inderdaad wel bij dat het ook bereikbaar en verleg-baar blijft. Het 'eruit halen' is daar ook wel belangrijk bij inderdaad.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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| Q1d | I  | Je had het er al even over, het is niet direct mijn volgende vraag maar één van mijn volgende vragen. Dus ik skip daar direct even heen. In mijn onderzoek definieer ik flexibiliteit als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. Nou die ingreep benoemde al een beetje. En ik ben benieuwd wat voor jou een ingrijpende ingreep is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P8 | Ja! Even denken. Nou ingrijpend vind ik als de gevel, als je echt iets aan de gevel moet veranderen. Niet zozeer omdat het beeld dat wij zo hebben bedacht, dat dat heel mooi is en dat altijd maar zo moet blijven, maar omdat de gevel gewoon heel duur is. De gevel is één van de duurste onderdelen van het gebouw. Dus als je daarin gaat zitten slopen, dan, dat is erg kostbaar. Dus je moet eigenlijk zorgen dat de gevel alles, al die variatie, die toekomstige flexibiliteit op kan nemen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I  | Dus je zegt eigenlijk dat de ingrijpendheid van een ingreep te maken heeft met hoe kostbaar die is?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P8 | Ja, precies! Dat zeg ik, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | I  | Dus als een renovatie intern, dus niets met de gevel te maken, maar wel heel kostbaar is, dan is die nog steeds ingrijpend?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P8 | Ja dat klopt. We zijn op dit moment ook bezig met de transformatie van een oude bejaardentehuis. Je kent dat misschien wel, uit de jaren 70 en 80 met allemaal van die hokjes en een binnen-gang. Verder een heel lelijk gebouw, maar als je er eenmaal mee bezig bent dan ga je het ook wel weer mooi vinden, dan ga je van het gebouw houden. En dat gebouw, die structuur, die heeft gewoon heel veel mogelijk. Want het is nu een corridor, met een midden-gang en aan weerszijde woninkjes. Wij maken er dan ook maisonnettes in, of zelfs eengezinswoningen, over twee verdiepingen en heel de diepte van het gebouw, zodat heel die corridor eruit gaat. We hebben allerlei dingen bedacht hoe wij binnen die structuur allemaal verschillend typologieën kan maken. En dan behoud je dus wel de draagstructuur helemaal. De rest van het gebouw wordt wel gestript, dus de gevel enzo gaat er allemaal uit. Dus de gevel enzo gaat er allemaal uit. Dus het is ook heel kostbaar. Maar alsnog komt het eruit, uit de bouwkostenberekeningen, dat het eigenlijk gewoon goedkoper is om het te slopen en gewoon opnieuw te maken. En dat is natuurlijk heel stom want het is natuurlijk ook verspilling. Want je hebt de structuur, die blijkbaar goed bruikbaar is, dat hebben we laten zien, dat je er allemaal andere dingen mee kunt doen. En dan toch is dat dan duurder! Terwijl je denkt, hé de fundering ligt er al, de wanden staan er al, de vloeren liggen al. Dan denk je van hoezo dan eigenlijk? Daar zijn wij ook net mee bezig, hoor. Dus ik kan jou nu niet zo oplepelen waar dat dan aan ligt. Dus dat zijn ook weer die kosten. En dan is het van nou die zijn dan voor de woningcorporatie en die vindt dat ook heel belangrijk, dat dat gebouw hergebruikt wordt. Dat past gewoon in hun imago en het is natuurlijk ook zonde en het heeft ook met de buurt te maken, want het is minder ingrijpend dan als je alles sloop. Maar dat is dan een andere overweging, het is niet de kostenoverweging. Ze hebben het ervoor over om er meer geld voor te betalen. Dus dat is dan natuurlijk heel goed en bijzonder. Alleen het gekke is dus dat dat alleen financieel gezien nog niet de slimste optie is. |
|     | I  | En komt dat door hoe het gebouw oorspronkelijk ontworpen is? Doordat het, tussen aanhalingstekens, moeilijk gemaakt is om het te renoveren, aan te passen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P8 | Ja, ook wel want het heeft heel veel geveloppervlak, dus dat klopt. Dat is wat ik net zeg, gevels zijn heel duur. Dit is een langgerekt gebouw, ja het ziet er eigenlijk heel gek uit. Het is een soort slingerend volume. Echt zo'n zeventiger jaren plan. Dus het heeft heel veel geveloppervlak. Dus je kunt hetzelfde aantal woningen in een veel compacter volume maken en dan heb je veel minder gevel en dus zijn de bouwkosten lager. Wat ik net al zei de gevel is heel bepalend voor de bouwkosten. Dus dat hebben we ook nog onderzocht, zou je in dat gebouw, een gebouw dat alle kanten op meandert, zouden we misschien de zijpoten wel moeten slopen? Al dat soort varianten hebben we ook nog bedacht. En die combinatie van disciplines, van én slopen én renoveren in één plan, dat is dan ook weer lastig. Maar dat is dan ook weer een beetje aannemer afhankelijk. Want ja je hebt gewoon aannemers, die doen het gewoon graag op zo'n manier en de ander doet het weer op die manier. Dat de bouwers allemaal een beetje hun eigen expertise hebben. Dat zie je sowieso wel. De ene aannemer wil graag alle dragende wanden met een tunnelsysteem maken, ook al zijn het maar, en het tunnelsysteem is eigenlijk pas                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |



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|    | <p>rendabel als je meer dan veertig woningen bouwt ofzo. Maar je hebt ook aannemers die zweren gewoon bij zo'n tunnelsysteem en die willen bij twintig woningen al tunnelen. Terwijl de andere de bouwwanden in kalkzandsteenblokken liever wil metselen, ook al zijn het zestig eenheden. Dat merk je ook, dat het heel erg afhankelijk van de bedrijven is, wat de mogelijkheden zijn. Dus daar moet je dus eigenlijk ook zo'n aannemer op selecteren. Ja, logisch natuurlijk, dat er één uitzoekt die die expertise heeft. Maar als je dan zegt, waar ligt het dan aan die kosten. Dat is dus enerzijds die gevel, maar anderzijds ook het hele nieuwe inbouwpakket. Want je hebt dan bestaande vloeren, die zijn maar zo dik [gebarend], want die zijn in 1970 gebouwd en toen had je nog niet die geluidseisen. Maar dan moeten we wel ineens aan de hedendaagse geluidseisen voldoen en dan moet er zo'n pakket op [gebarend]. Afwerkvloer. En daar moeten alle leidingen in. En dat is dan weer veel duurder. Dus dat is toch ook weer op installaties veel duurder dan als je dat in één keer in een nieuwbouwplan zou oplossen en je zou de woning scheidende vloeren al meteen die dikte geven die voor het geluid noodzakelijk zijn. Dus dat zit ook heel erg in dat afbouw verhaal. Dus als jij, in je onderzoek met je vloeren. Hoe zou jij dat dan doen? Want eigenlijk, meestal is het zo, je hebt een vloer en daar komt een afwerkvloer op en daar zit verwarming in en er zitten nog andere dingen in. Maar op het moment dat je die vloer van kanaalplaten maakt of wat dan ook. In ieder geval je wil die vloer kunnen hergebruiken, dan wil je eigenlijk ook dat je die afwerkvloer dat je die er ook af kan halen. En het is veelal toch, dat als er kanaalplaatvloeren gebruikt worden, dat er in het werk gewoon een zandcement vloer overheen gegoten wordt. En dan moet je er nog een drillboor in zetten als je het wil afbreken. Ik denk daar zit het dan, dat je iets in die afwerkvloer bedenkt dat je dat ook kunt demonteren.</p> |
| I  | Ja dat zou ideaal zijn inderdaad.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P8 | <p>En dat dat in een enigszins beperkt pakket is, qua hoogte. Als dat weer te hoog is, of je te hoog? Het is natuurlijk nooit te hoog. Maar dat dat gebouw niet veel te hoog wordt. Want dat zijn allemaal kuubs en dat kost ook weer geld. Dat geeft verder niet, maar het is dus heel erg belangrijk wat wij allemaal willen. Kijk als iedereen het gewoon wil, ik denk wel een van wat als de overheid nou gewoon bepaalde dingen verplicht stelt. Dan gaat de bouw vanzelf wel mee, want als het moet, dan moet het. En soms wordt er wel over gepraat, kunnen we niet dat of dat. En ik denk, ja die bouwbedrijven die gaan dat misschien wel doen, maar niet zo snel. Want ze moeten natuurlijk ook gewoon geld verdienen. Dus soms denk ik wel eens, kun je niet gewoon heel veel dingen gewoon verplicht stellen. Gewoon als een soort dictatuur. Dan is het zo geregeld. Want als dat moet, ja dan gaat iedereen dat doet. En binnen de kortste keren zijn er allemaal slimme dingen voor bedacht.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| I  | Dan gaan ze innoveren en dan wordt het efficiënt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P8 | Ja, precies. Maar, even kijken, wat heb jij dan tot nu toe? Kijk jij ook, denk jij ook aan oplossingen, ontwerp je ook oplossingen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| I  | <p>Dat is wel het idee. Zover ben ik nog niet, ik ben nog niet begonnen met het echt ontwerpen van oplossingen. Daar ben ik wel binnenkort aan toe. Maar ik ben nu nog mijn theoretisch kader aan het afronden, zeg maar. Dus ik heb onderzoek gedaan naar wanneer is iets flexibel, welke technische eigenschappen maakt het flexibel. Ik heb gekeken naar welke oplossingen bestaan er al. Dus er zijn in Nederland en in de rest van de wereld al een aantal vloeren ontworpen die een bepaalde vorm van flexibiliteit hebben, maar die soms nog niet echt doorgebroken zijn en nog niet breed toegepast worden. En dan heb ik gekeken naar de eigenschappen die zij daarin meegenomen hebben. En ik ben dus dit soort interviews aan het doen om informatie en ideeën te verzamelen. Vanuit verschillende vakgroepen worden verschillende dingen als belangrijk of als uitdagingen gezien. Dat is heel interessant om mee te krijgen. Maar, ja. Ik ben wel van plan om oplossingen te ontwerpen. Ik ben ze nog niet liggen, zoals je begrijpt. Er zijn wel een aantal categorieën in oplossingen, die je zou kunnen onderscheiden. Je hebt de holle vloer, zoals ik dat noem. Dan heb een constructieve vloer, waarin binnen die hoogte een soort lege ruimte is waarin je de installaties kunt verwerken. Dan zit je nog wel met de uitdaging van de afwerkvloer, dat je daar nog steeds door heen wil kunnen en zoals je zei in sommige gevallen zitten de installaties daarin. En je hebt natuurlijk, wat op kantoren meer gebruikelijk is, de verhoogde vloer en het verlaagd plafond. Dat zijn eigenlijk de twee hoofdzakelijke opties. Of je verwerkt</p>                                                                                                                                                                                                                                                                                                                                                                                               |



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|    | de installaties in een holle ruimte in de vloer of je legt ze erop of eronder, als je het flexibel wilt houden. De andere optie is natuurlijk erin storten, maar als je het flexibel wilt houden is dat geen optie. Dan kun je er niet echt meer bij. Dus dat zijn een beetje de twee oplossingsrichtingen en die hebben allebei hun uitdagingen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P8 | Dat heeft natuurlijk alles ook met die installaties te maken. Want tegenwoordig werken we ook een stuk minder met radiatoren maar met de vloerverwarming, de lage temperatuurverwarming in combinatie met de warmtepomp enzo. Dat zou je natuurlijk ook in het plafond kunnen doen, alleen dan is de warmteafgifte anders. Dan is het daarboven warm en ja. Maar dat wordt ook wel gedaan. Dus dat is op zich nog wel een gedachte, dat je zegt die afwerkvloer die heb je niet, je hebt een plafond. Dat kan je misschien veel makkelijk los eronder hangen, want dat hoeft aan minder eisen te voldoen. Daar hoeven geen kasten of mensen op te staan. En dat is misschien gewoon een soort systeemplafonnetje.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Ja dat is denk ik het voordeel van een verlaagd plafond ten opzichte van een verhoogde vloer, dat je er niet op hoeft te staan. En je kunt er eigenlijk altijd makkelijk bij want er staan geen banken op, geen kasten op, je hoeft niets te verschuiven.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| P8 | Dat is ook slim daaraan. Als je een plafond maakt, als je er een plafond onder hangt, dan kun je in wezen alle installaties achter dat plafond kwijt. Dan hoeft je niks in de vloer op te nemen, dan kun je ook een massieve vloer nemen. Alleen het totaalpakket wordt dan misschien dikker. Maar misschien is dat wel heel slim, heel economisch. Want jij richt je nu dan ook vooral op betonvloeren of kanaalplaatvloeren? Of dat niet persé?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I  | Vanuit mij hoeft dat niet persé. Het is wel een uitgangspunt dat ik sowieso meeneem omdat er veel gebouwd wordt in beton. In mijn vooronderzoek heb ik wel houtvloeren en ook stalen vloeren meegenomen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| P8 | Ook stalen vloeren?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| I  | Ja er zijn een aantal. Het voordeel van staal is dat het vaak heel demontabel is. Maar je ziet het niet heel veel. En houten vloeren zijn natuurlijk ontzettend hip.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| P8 | Ja dat is hip, dus dat is nu onbetaalbaar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| I  | Er zit daarmee ook wel heel veel onderzoek in, dus wellicht dat daar, dat die ontwikkelingen relatief snel gaan.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| P8 | Maar als je een stalen vloer maakt, dan maak je gewoon balken en daar leg je van die platen overheen, van die zwaluwstaarten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| I  | Ja. Dan moet je wel rekening houden met trillingen en geluid en dat soort dingen. Er zit natuurlijk niet zo heel veel massa in. Je ziet ook wel redelijk veel, bij flexibele vloeren, composiet staal en beton vloeren. Dus dat je een massa laag hebt van beton met stalen liggers erin gestort.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P8 | Eigenlijk hoe het ook in de bedrijfshallen altijd al gedaan wordt. Een staalconstructie en dan huppakee kanaalplaten erin. En die kanaalplaten kun je natuurlijk voorspannen, dus dan kun je hele grote overspanningen maken, 12 meter ofzo of weet ik veel hoeveel. Dat is dan natuurlijk slim. Dus dat is eigenlijk heel slim. En dan is gelijk natuurlijk de vraag, hoe maak je dan wanden daarin. Of in dit geval, als je woning maakt, hoe zorg je dan dat je woning scheidende wanden goed kunt maken. Want daar zit natuurlijk een potentieel lek ook, als de vloer doorloopt. Hoe zorg je nou dat dat goed aansluit. Dat veronderstelt eigenlijk dat je én een afwerkvloer maakt daar los op én een plafond dat je helemaal een soort doos in een doos maakt. Ik weet wel, hier in [middelgrote Nederlandse stad] valk bij het station, wordt zo, hoe heet dat, [gebouwnaam]. Dat is misschien interessant om naar te kijken. Daar weet ik niet veel vanaf hoor, maar ik weet wel dat daar ook, daar hebben ze ook slimme dingen gedaan met bijvoorbeeld badkamers die helemaal geprefabriceerd zijn. Die daar als één af doosje, meteen goed en al, met al het sanitair erin, erin gehesen worden. Ik weet dat [grote Nederlandse aannemer] dat gebouwd heeft. Maar ik weet er verder niet veel van, hoor. Als je daar in één keer een badkamer in zet met vloer en al. Dan zit ik nu te denken, hoe zit dat dan met de rest van de afwerkvloer. Ik weet niet helemaal of dat echt vanuit de circulaire gedachte ontworpen is, of alleen maar economisch. Er zitten volgens mij enorm veel kamers in, dus er zit ook enorm veel repetitie in. En dan wordt het ineens economisch haalbaar om dat op zo'n manier te doen. |
| I  | Ja, massaproductie in dat geval.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| P8 | Maar dat hoorde ik via via en ik dacht misschien is dat nog wel interessant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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|---------------------------------------|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Q1c                                   | I  | Ik heb nog een vraag voor je en die luidt: wat zijn de huidige ontwikkelingen in jouw vakgebied op het gebied van flexibiliteit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | P8 | Eigenlijk, nou wat ik al zei, omdat wij binnen de woningbouw zitten, dat is heel erg gedacht vanuit vaste stramien. Van tunnels we het, maken we het helemaal in prefab, dat hout komt nu een beetje. Wat ik zei van [projectnaam] waar we nu mee bezig zijn, in staal dat is dus redelijk uitzonderlijk. Maar het komt dus wel. Het is wel dat dat nu, het komt in ieder geval op de agenda, laat ik het zo zeggen. En dat is eigenlijk ook dan ingegeven door een gemeente. Dus de ambities, niet zo zeer de ambities van de bouwer en ook niet meteen de ambities van de architect, moet ik eerlijk bekennen. Ja die vinden het natuurlijk heel leuk en interessant om het te doen, maar het heeft voor ons geen zin om iets te tekenen waar niemand op zit te wachten, zeg maar. En wij zitten altijd aan hele strakke budgetten. We moeten een ontwerp tekenen en je weet het moet voor zus en zoveel gebouwd worden. Ja dan heeft het geen zin om een staalconstructie te tekenen, want ik weet dat is gewoon dat is te duur. Dus het is een beetje dom om dat dan te gaan tekenen. Maar dit plan is er dus ook, door de overheid wordt eigenlijk een soort ambitie geformuleerd. Dus het is eigenlijk een beetje, het is niet echt een eis maar het wordt echt wel ten eerste op prijs gesteld. En dan komt het wel op gang.                                                                                                                                                                                                     |
|                                       | I  | Hoe stelt de overheid deze eisen? Doen zij dat door middel van beleid of zetten ze er subsidie op of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                       | P8 | Nee het zijn eigenlijk eisen die in, vaak worden in het stedenbouwkundig plan eisen met betrekking tot duurzaamheid gesteld. Dus het zijn ook geen harde eisen, maar het staat er allemaal wel. Van je moet daar en daar aan voldoen. Het is niet in wetgeving gevat. En het is dan vaak bij plannen dat er dan supervisors aangesteld worden om dat ook allemaal in de gaten te houden. Dus dan merk je, als de ambities hoog zijn en iedereen neemt het ook serieus, dat is ook heel belangrijk, het is wel vaker dat overheden iets stellen en dat er wordt gedacht ja dat zeggen ze wel maar de soep wordt niet zo heet gegeten en dan komt er toch niks van terecht. Dus het is vaak wel zo dat gemeentes die een beetje wat in hun mars hebben, dat dat toch wel van de grond komt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Topic 2: Flexibility of floors</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Q2a                                   | I  | Interessant. Nou mijn volgende vragen die gaat echt over vloeren, we hebben het tot nu toe meer over gebouwen in het algemeen gehad. De eerste vraag: wat is een vloer voor jou?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | P8 | Een vloer? Vaste grond onder je voeten. Veiligheid, zo van nou voelt goed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                       | I  | Helemaal mooi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                       | P8 | Dat is een vloer voor mij. Een vloer voor mij is niet een scheidingsconstructie. Zo van wat fijn dat er hier iets onder zit tussen wat eronder zit en hier. Dat is het niet voor mij. Maar dat is misschien voor andere mensen heel anders. Voor jou, wat is voor jou een vloer?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | I  | Ik heb ondertussen al met een aantal mensen hierover gesproken en ik denk dat de dragende functie, de constructieve functie, toch een hele belangrijke is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                       | P8 | Ja en verder een vloer. Je hebt in een woning toch heel veel vloeren, dus het bepaalt voor een heel groot deel ook de sfeer in een huis. Ja vooral de gevelopeningen natuurlijk en het uitzicht en de indeling. Maar die vloer toch ook wel. Maar ja, in het vakgebied waar ik mij beweeg is dat, ja. Wij bouwen ook wel eens chique villa's, daar niet van. En dan kun je natuurlijk helemaal alles ontwerpen zoals je wil. En de seriematige woningbouw is natuurlijk allemaal casco. Maar die vloeren, het is vooral inderdaad, nou wat ik zei, het is vooral. Ja het is ook hoe die vloer eruitziet. Kijk, stel als je iets goeds kunt bedenken voor die afwerkvloer, stel je legt een houten afwerkvloer erop, panelen of weet ik veel wat, waar verwarming in zit. En dat hout heeft een mooie uitstraling. Want dat is een mooie berken multiplex afwerklaag, ik zeg maar wat. Dan kun je in één keer natuurlijk in een woning een mooie houten vloer hebben. Hoef je geen vloerbedekking neer te leggen, of een paar losse kleden. Dat biedt natuurlijk ook wel kansen, als je in zo'n afwerkvloer denkt, dat je daarmee ook gelijk de woning kan stofferen, zeg maar. Omdat we het natuurlijk net hadden over vloeren en dan gooi je daar een in het werk gestorte vloer overheen, maar dan is die vloer natuurlijk niet meer demontabel. Dus dat je er iets op kunt leggen, wat je ook weer uit elkaar kunt halen. Dan kun je natuurlijk ook iets gaan zeggen over het uiterlijk daarvan. Dus dat is misschien wel heel mooi. |
|                                       | I  | Ja, absoluut.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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| Q2b                                          | I  | Mijn volgende vraag: kun je met vertellen over de huidige staat van flexibiliteit in het ontwerpen van vloeren?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                              | P8 | Nou daar kan ik heel weinig over zeggen, denk ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                              | I  | Dat mag ook.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                              | P8 | Het gaat weer om de flexibiliteit in het ontwerp of in de praktijk. Want als je een tunnelbeskisting hebt, waarbij de wanden en de vloeren in één keer gestort worden, dan kun je natuurlijk van alles in die vloer gooien, wat je maar wil en op welke manier dan ook. Ja je moet dat de leidingen elkaar niet te veel kruisen en dat je niet te weinig dekking op die leidingen hebt. Maar op termijn is er natuurlijk de flexibiliteit, en je bedoelt natuurlijk de flexibiliteit op termijn. Is dat natuurlijk nul flexibel. En de kanaalplaten, ja die zijn natuurlijk hol. Dus dan kun je denken hé in die holte kan je natuurlijk van alle in stoppen. Maar als het er eenmaal ligt, kun je er natuurlijk niet meer bij. Dus, als je het hebt over vloeren die, ja een beetje in de kantorenbouw, hè. Dus dat je toch een soort, ja vroeger noemden ze dat een computervloer, dus twintig jaar geleden. Dus dat je een afwerkvloer had, waar alles in zat, alle leidingen, en die werd dan gewoon neer gelegd. Zoiets zou je dan ook in de woningbouw moeten gaan doen.                                                                                      |
|                                              | I  | Ja de verhoogde vloer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                              | P8 | Ja, de verhoogde vloer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                              | I  | Ja dat is een optie.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Q2c                                          | I  | Nou ja, dan mijn volgende vraag. Welke trend zie je in de ontwikkeling, binnen de architectuur, binnen jouw vakgebied, die invloed zouden kunnen hebben op vloersystemen? In het algemeen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                              | P8 | Nou de trend om circulair te bouwen, of die wens in ieder geval. Dat is natuurlijk dan heel erg van invloed daarop. Omdat vandaag de dag, in woningbouw, zijn die structuren gewoon helemaal niet flexibel. Ja soms wordt er wel gezegd dat het zo is, maar dat is eigenlijk gewoon helemaal niet zo. Ook niet als je met prefab casco's werkt of met kanaalplaten, dat is toch vaak helemaal niet flexibel op langere termijn. Maar als je gaat denken vanuit circulariteit, dan moet het wel, dan moet je het gewoon uit elkaar kunnen halen. Dus dan is denk ik gewoon jouw onderwerp een super interessant onderwerp! Dat is gewoon heel erg actueel. En dat betekent ook dat daar heel veel vragen openliggen, heel veel mensen weten het allemaal nog niet. Mensen weten helemaal niet waar ze het over hebben. Iedereen praat maar over circulariteit. Maar wat dan, ja, vaak is het ook een beetje een soort verhaaltje. Een beetje waar we mee begonnen ook, hè. Ons bureau zit in een heel oud pand. Dat is natuurlijk niet circulair gebouwd, heel traditioneel gebouwd, maar het is wel super duurzaam omdat het eeuwig meegaat. Nou niet eeuwig, maar. |
|                                              | I  | Maar wel vrij lang!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                              | P8 | Ja, het gaat al meer dan vierhonderd jaar mee. En dat is gewoon omdat het heel ruim opgezet is. Want het is hoog, dus je kan er goed een kantoor van maken. Je kunt er ook nog een vloer in leggen als je dat zou willen. Want, ja de ruimte waar ik zit, die is viereneenhalve meter hoog. Dus ik denk dan altijd stiekem, de beste manier om duurzaam te bouwen is om dingen te maken die gewoon heel lang meegaan. Meer dan dingen circulair maken zo van nou we breken het weer af na een bepaalde tijd.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                              | I  | Als je het hebt over heel lang meegaan, dan kun je denken aan het hele gebouw in zijn geheel gaat heel lang mee of aan de elementen gaan heel lang mee. Dan ben je weer demontabel bezig.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                              | P8 | Precies. Daar heb je natuurlijk gelijk in. Dat is natuurlijk veel meer de circulaire gedachte. Nee dus ik denk, jouw onderzoek is gewoon heel actueel, jouw onderwerp.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Topic 3: Opportunities and challenges</b> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Q3a                                          | I  | Mijn laatste onderwerp zijn de kansen en uitdagingen. Zoals je kunt verwachten komt er een tweeluik aan vragen. Eerst wil ik je naar de kansen vragen en dan naar de obstakels die je wellicht voorziet. Dus de eerste vraag is: welke kansen voorzie je voor flexibiliteit met betrekking tot jouw vakgebied en vloersystemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                              | P8 | Ja, nou ik denk dat als je inderdaad, nou wat ik aan het begin zei, als wij een huis ontwerpen proberen wij daar zoveel mogelijk gebruiksmogelijkheden in te voorzien. En dus je in je eetkamer dat je je tafel niet persé hier of daar hoeft te zetten en dit of dat. Dus dat vinden wij altijd wel heel belangrijk en juist ook met het idee voor de toekomst. Dan kan dat gebouw lang mee. Als de gezinnen groter worden, kun je er een kamer bij maken. En als de gezinnen kleiner worden of mensen worden slecht ter been dan kun                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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|     |    | je wanden verplaatsen. Dus dat proberen we altijd al. Dus het moment dat je meer vanuit die circulariteit gaat denken dan is dat natuurlijk heel interessant. Ja je moet misschien oppassen dat je daar niet in door schiet. Dat je je afvraagt moet alles dan in een gebouw circulair zijn. Je kunt je natuurlijk ook voorstellen dat je zegt, nou we maken het casco niet circulair. We maken het casco zo groot of zo ruim dat je daar misschien wel 200 jaar mee verder kan in plaats van 50 jaar. Maar de inbouwpakketten, die maken we circulair. Dus als je zegt van goh het moet flexibel zijn, dan gaat het misschien niet over elk aspect van het gebouw. Dat is een beetje afhankelijk van de functie. Dat is een beetje wat we net zeiden over het pand waar ik dan zit. Je zei dat je er ook voor kunt zorgen dan onderdelen circulair zijn en dat je dus die kozijnen ooit weer kan hergebruiken. Maar dat kan ik me voorstellen dat dat ook interessant is, hoe ga je die combinaties van dingen maken. Dit of dat of dat, dat is slim als dat circulair is. Misschien ook omdat de levensduur daarvan minder lang is dan een ander onderdeel. Want dat heb je natuurlijk, las ik dat ook niet in jouw stuk? Op het moment dat je leidingen instort, dat die leidingen gaan een stuk korter mee dan de vloer.                                                                                                                                  |
|     | I  | Ja absoluut.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | P8 | Ja, dus dat is natuurlijk heel stom. Dan moet je heel die vloer gaan afbreken terwijl die vloer nog goed is. Dus dat is dan wel een hele interessante gedachte, dat je die combinaties gaat maken van circulariteit. En ik denk, dan is het gewoon heel belangrijk dat het casco, de structuur, die hoeft dan denk ik nog niet eens zo heel circulair te zijn. Maar die moet vooral heel goed zijn, en royaal. Dat je weet, daar kun je tot in de lengte van dagen ook andere functies aan toe kennen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | Dat die flexibiliteit faciliteert, in plaats van dat die zelf flexibel is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P8 | Ja precies, dat is dan misschien wel slimmer. Maar dat is misschien ook wel afhankelijk van de vraag, waar er behoefte aan is. Maar dat is wel een hele interessante gedachte.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Q3b | I  | Nou dan ga ik natuurlijk naar de tweede kant van deze vraag en dat is welke uitdagingen of obstakels zie je voor flexibiliteit met betrekking tot jouw vakgebied en vloersystemen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | P8 | Ja, ik denk dus eigenlijk, een beetje een saai antwoord, de bouwkosten. De uitdaging is gewoon dat de hele bouw, die best nog heel traditioneel is, dat die daarin meegaat. De noodzaak voelt om daarin mee te gaan. Dus het voorbeeld wat ik noemde met dat project waarvan we keken doen we het in staal of in beton? Ja in staal is het 67 of 70% duurder. Dat je denkt ja hè hè dat antwoord had ik ook wel verwacht, snap je? Het is een soort andere manier van denken. En zolang je niet op die andere manier denkt, ja dan is het natuurlijk duurder. Ja dat klinkt een beetje stom. Ik denk dat dat belangrijk is, dat zo'n hele branche op een andere manier gaat denken. En als dat niet gebeurt, dan zal er nog steeds met die circulariteit wel doorgang vinden. Maar dan is het heel erg meer dat het opgelegd is door overheden. Omdat er dus ook geld voor vrij gemaakt wordt, of subsidie. Of dat het alleen maar voor de hele chique dingen gaat gelden, voor de dure woningen. Maar als je gewoon sociale huurwoningen bouwt, dan niet. Waar de budgetten gewoon meer onder druk staan. Dus dat denk ik, dat dat de uitdaging is. De uitdaging is niet of een architect iets slims of iets moois kan bedenken, dat komt wel goed. Die architect moet altijd een beetje in toom gehouden worden, dat ie niet te veel gekke dingen gaat doen. Nee, maar ik denk dat dat het gewoon is, dat er een soort omslag in denken plaats moet vinden. |
|     | I  | Dus het kan wel, maar mensen moeten het wel willen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P8 | Ja, ze moeten het gewoon willen! Als je het eigenlijk stiekem niet wilt, kun je nog net doen alsof je het wel wilt, maar dan komt de aap uit de mouw en eigenlijk wil je het gewoon niet. Dan komt het er gewoon niet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | I  | Ja dat is jammer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

Table B.12: Transcription interview P9 & P10

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|-----------------------------------|------------------------|--------------------------------------------------------|
| Interviewee                       | P9                     | Project developer at a large Dutch housing corporation |
| Interviewee                       | P10                    | Project developer at a large Dutch housing corporation |
| Date and time                     | April 28 <sup>th</sup> | 15:00                                                  |
| Topic 1: Flexibility of buildings |                        |                                                        |

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| Q1a | I   | Kunnen jullie mij vertellen over de ontwikkelingen in de bouw die voor jullie of voor jullie vakgebied van interesse zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|     | P9  | Dat is een vrij brede vraag.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | I   | Klopt, dit is een opwarmer. Hij mag ook vrij breed aangesneden worden. Eerst even een beetje de context schetsen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P9  | Nou ja, de ontwikkelingen die nu actueel zijn. Duurzaamheid, daar speelt natuurlijk een hoop. Installatietechniek, maar ook het voorkomen van afkoeling en opwarming van woningen. En wij houden ons ook specifiek bezig met flexwoningen. Met tijdelijke woningbouw, waarbij wij denken dat modulair bouwen daar goed bij aansluit. Voor mijzelf vertaal ik hem even zo. [P10] heeft daar misschien een ander beeld bij? Dat is zoals ik het zie. En ja in de breedte, vind ik zelf, maar dat sluit dan weer aan bij jouw onderzoek, de toekomstbestendigheid van gebouwen en het hergebruik, transformatiebestendigheid van gebouwen, vind ik een interessant iets. We zitten hier in [grote Nederlandse stad] in een kantoor in [gebouwnaam], waarbij je de structuur van het oude pakhuis nog ziet. Het is een pakhuis, dat getransformeerd is nu, naar kantoren. Ja dit is wel gewoon een toekomstbestendig gebouw gebleken. Achteraf gezien, want volgens mij is het nooit zo gebouwd. Dat vind ik wel een interessante opgave in de bouw, nu. |
|     | P10 | En van mijn kant, een beetje aansluitend, ik ben het eens ook wat [P9] zegt. Als je ook kijkt naar de uitdagingen waar we in de bouw voor staan, dan is de bouw ook één van de meest traditionele, toch wel wat logge ontwikkelingen. En ik denk dat langzaam maar zeker merk je toch steeds meer de omslag. En daarin moeten we gewoon af en toe even iets anders denken. En ik denk dat wij als mensen zijn heel erg gewend aan ons huisje boompje beestje, en op het moment dat die mindset gaat veranderen, dan gaat ook de bouw veranderen. Beter nadenken en flexibeler nadenken over hoe woningen meegaan, dat is een hele grote opgave maar verschrikkelijk belangrijk. Dus daar sluit ik me helemaal bij aan.                                                                                                                                                                                                                                                                                                                               |
| Q1b | I   | Mooi.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | I   | Nou dan gaan we door naar mijn volgende vraag. En die is: kunnen jullie mij vertellen hoe er vanuit jullie vakgebied naar flexibiliteit of aanpasbare gebouwen gekeken wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P9  | Nou er wordt op meerdere schaalvlakken gekeken naar flexibiliteit. Met name over de gebouwen zelf, we hebben ons project met flexwoningen hebben we dat woningen verplaatsbaar moeten zijn van locatie eigenlijk. Maar flexibel in gebruik, ja dat is niet altijd, laat ik het ander zeggen. Binnen de budgetten en de aandacht van de sociale woningbouw, is dat nog wel een kind van de rekening van de budgetten denk ik. Ik zie nog niet zoveel in onze recente projecten, dat we aanpasbaar of zo bouwen dat het makkelijk te schakelen of te transformeren is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | I   | En waar ligt dat aan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P9  | Op dit moment denk ik dat het binnen de budgetten die we hebben, het al lastig genoeg is om een standaard woning te ontwikkelen. Dat er ook nog een beetje leuk uit ziet, dat is wel waar [bedrijf waar P9 en P10 voor werken] naar streeft. Dat het er ook nog wel goed uit ziet. Dat het niet zomaar een blokkendoos is. Omdat dat ook een effect heeft op hoe mensen het gebouw gebruiken en hoe je je daar voelt en hoe je daar woont. Maar dan is het denk ik weinig, daar is mijn aanname dat flexibiliteit in overmaat of in extra installatieruimte, dat dat altijd wel kostenverhogend is. Dat is de aanname die ik daar zelf dan bij doe. Laat ik het eventjes dan zo formuleren.                                                                                                                                                                                                                                                                                                                                                          |
|     | I   | Ja precies. Nou dat is natuurlijk een veel voorkomende aanname. Wat ik lees uit de literatuur, ik heb daar nog niet zelf direct ervaring mee, is dat er verwacht wordt dat het aan het begin meer geld kost, maar dan in je loop van de tijd dat je het eruit haalt, als het ware. Ik vraag me af hoe hier in jullie branche naar gekeken wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P9  | Zo kijken beleggers er zeker wel naar. Maar in de sommetjes rekenen we er niet zo naar. Want wij als corporatie zijn natuurlijk ook een belegger. We kijken naar een soort van timeframe, de eerste 15 jaar van de exploitatie. Daarop rekenen wij iets door, daar hebben we een rendementscijfer dat daaruit komt. En dat is hoe we daarnaar kijken. En dat is nog relatief korte termijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | I   | Gaan jullie er, tussen aanhalingstekens, vanuit dat een gebouw 15 jaar rendabel moet zijn, of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |



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|------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | <b>P9</b>  | Nee nee nee, zeker niet. Dus je rekent de huurinkomsten van de eerste 15 jaar en de eindwaarde in jaar 15, alsof we hem dan zouden verkopen. Dat doen we niet, maar zo rekenen we even. Daarmee rekenen we een IRR, een Internal Rate of Return uit. Dat is een rendementsgetal. Dat zetten we af tegen onze norm. Dus op die manier toetsen we onze gebouwen. Dus we kijken in die toets niet naar jaar 40 of 50, waarin op die locatie misschien geen behoefte meer aan wonen is, maar wel aan werken of andersom. Ik weet dat [bedrijf waar P9 en P10 voor werken], maar dat is in 2001 2002, het [gebouwnaam] gerealiseerd heeft [in stadsbuurt]. Daar was ik toen, in mijn eerste baan als junior ontwikkelaar betrokken, maar dan aan de ontwikkelaarskant. En dat was een gebouw waar wat overmaat in zat en wat flexibiliteit in zat. Waardoor je van werken naar wonen kan omklappen. Toevallig begreep ik van nu collega's bij [bedrijf waar P9 en P10 voor werken], dat het misschien wel binnenkort dat er een verdieping bedrijvigheid vrij komt, die naar wonen omgetransformeerd zal gaan worden. Dat wordt interessant om te zien of het gebouw gaat doen waar het voor bedacht is, inmiddels bijna twintig, meer dan twintig jaar geleden.                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|            | <b>I</b>   | Precies, dat is wel tof.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|            | <b>P10</b> | En ik kan daar nog even voor [bedrijf waar P9 en P10 voor werken] wat moeilijk wat aan toevoegen, want ik werk nu pas 2 weken. Maar als ik, mag ik een uitstapje maken even naar mijn vorige baan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|            | <b>I</b>   | Tuurlijk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|            | <b>P10</b> | Ik heb hiervoor voor een hotelbedrijf gewerkt. Waar er wel gekeken en niet gekeken werd naar flexibiliteit. Maar op een hele andere manier flexibiliteit, in de zin van daar bouwden we modules, compleet met interieur. Dus inclusief bed, alles, alles zit erin, vast ingezet. En daarvan was het idee dat je het op twee manieren kan gebruiken. Dus die module moet je na misschien 30 jaar of 40 jaar of op het moment dat het niet meer logisch is. Ook een beetje hetzelfde als voor woningen, een hotel heeft niet een eeuwig leven. Dus daar wordt ook een vrij korte, we rekenden meestal met 20 jaar terugverdientijd, met een restwaarde. Maar waar we wel naar keken, is die module. Die kan je natuurlijk op 20 jaar of 40 jaar of wanneer je wil er weer af halen. Maar ook het interieur moet helemaal flexibel kunnen zijn, in die zin dat over, weet ik veel, 15 jaar, is die fit-out helemaal uitgeleefd. Dan moet er een nieuwe fit-out in. En dat wil je niet aanpakken als renovatieproject, want dat heeft heel veel impact op je inkomsten. En in dat geval waren ze, en ik ben nu weggegaan terwijl ze midden in die hele transformatie zaten, maar daar werd op een gegeven moment, daar zat een heel concept achter van hoe kan je nou dat interieur helemaal flexibel maken zodat eigenlijk je renovatietijd zo kort mogelijk wordt gehouden. En dan maak je dus echt een verschil tussen je schil en je structuur en je fit-out. Maar dat is voor woningen natuurlijk wat minder van belang, want die lever je niet op met een bed en je hele meubilair en je behang. Maar ja dat zijn dus ook manieren waarop, denk ik, de bouw er in verschillende soorten lagen naar zou kunnen kijken. |
| <b>Q1c</b> | <b>I</b>   | Ja, herkenbaar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|            | <b>I</b>   | In mijn onderzoek, zoals ik al zei, definieer ik flexibiliteit als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder dat hierbij de noodzaak is voor een ingrijpende ingreep. En dan zou ik aan jullie willen vragen wat voor jullie een ingrijpende ingreep zou zijn. Waar zouden jullie die lijn trekken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|            | <b>P10</b> | Ingrijpend voor mij is het moment dat de functie echt verandert, dat is meestal wel echt ingrijpend. En als je kijkt naar gebouwelementen, heel specifiek bijvoorbeeld een wand, ik denk dat er een factor tijd aan zit. Hoe makkelijk, hoe snel kan ik dat doen. Weer denkend aan op een gegeven moment wil ik weer gebruik. Dus ik wil niet mijn hele muur moeten slopen en opnieuw opzetten. Ook als je kijkt naar circulair, vanochtend in een lezing die ik bijwoonde, ging het over CLT en het infresen van bijvoorbeeld leidingwerk. Ja eigenlijk word je CLT dan een stuk minder waard, want dat hout in ingefreesd. Dus het moment dat ik het wil hergebruiken zit je wel al meteen met een vast leidingenpatroon dat er helemaal ingefreesd zit. Dus dat voelt dan heel ingrijpend.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|            | <b>P9</b>  | Ik denk ook dat ingrijpende aanpassingen. Als je bijvoorbeeld een constructie van een gebouw, dat je tussen de constructie wat meer flexibiliteit hebt dan in de constructie zelf.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |



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|                                          | I   | Hoe bedoel je dat?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                          | P9  | Bij het aanpassen van een gebouw, als je de constructie moet aanpassen om een nieuw gebruik te faciliteren.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                          | I   | Dus de andere lagen aanpassen, als het waren, dat is wat minder ingrijpend. Maar de vaste constructie dat is ...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                          | P9  | Ja, dragende wanden... Soms gevels, het hangt er een beetje vanaf hoe je zwaar je een transformatie insteekt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                          | I   | En is dat ingrijpend omdat daar meer werk bij komt kijken, of meer geld, of is dat meer een soort van gevoelskwestie, dat voelt ingrijpend?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                          | P9  | Nou het is vaak een combinatie van meer werk en dus ook meer geld dat je erin steekt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                          | I   | Ja dat klinkt logisch.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Topic 2: Flexibility of floors</b>    |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Q2a                                      | I   | Oké, nou dan wil ik doorgaan op mijn tweede topic. Dat is de flexibiliteit van vloeren specifiek. Nou jullie hebben in de mail denk ik gelezen dat mijn onderzoek specifiek over vloeren gaat. En waar ik dan naar kijk is de flexibiliteit van de bouwinstallaties laag in combinatie met de dragende functie van de vloer. Zoals jullie waarschijnlijk weten, worden de installaties vaak ingestort in de vloer en dan kun je er moeilijk bij, kun je moeilijk aanpassen, uithalen, upgraden, wat je er ook mee zou willen doen. En de vraag die ik hierbij heb voor jullie is: hoe zou de flexibiliteit van vloeren voor jullie van toegevoegde waarde kunnen zijn? Binnen jullie vakgebied.                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                          | P10 | Ik kan er wel een aantal noemen, denk ik. Sowieso, je gaf het in het begin al een beetje aan, circulair, op het moment dat je gaat scheiden, en zoals ik net al zei, stel dat je constructieve vloer een CLT-vloer is en ik mijn leidingen daar gewoon op kan leggen met daarboven een zwevende vloer. Da heeft dat CLT een veel hogere waarde, restwaarde, op het moment dat we zeggen we willen er iets anders mee gaan doen. Want er zitten geen gaten en geen sleuven in. Akoestisch lijkt het me ook heel fijn, omdat je natuurlijk je schil, je constructieve laag komt nooit bij burens, je hoeft nooit door die laag heen. Om dan bijvoorbeeld afvoeren die dan geïsoleerd en dan heb je weer een geluidskleef... Nou ik kom uit hotels, dus dit was één van de grote problemen altijd. Daar heb ik heel veel voorbeelden van. Dat zijn even, als ik erover nadenk, en uiteraard de flexibiliteit. Op het moment dat ik erbij moet en je alleen aan je toplaag hoeft te zitten of hoe dan die afwerking moet zijn, ja dat scheelt natuurlijk een heleboel tijd en inspanning. Dat zijn mijn topics. |
|                                          | P9  | Ja daar sluit ik me wel bij aan. Ik zit dan wat meer in een betonconstructie te denken. Maar daar geldt hetzelfde voor. Als je daar een scheiding maakt tussen het constructieve beton en de dekvloer, waar je flexibel bent met je leidingen, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                          | I   | Is het iets waar jullie wel eens tegenaan lopen? Dat je de installaties wil aanpassen of upgraden na zeg twintig jaar, dan zijn ze meestal outdated, geloof ik. Dat dat handig zou zijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                          | P9  | Nou ja, in die periode pas je dan volgens mij eerder de ketel, de cv-ketel, het apparaat aan. Maar het leidingwerk hoeft je niet direct aan te passen in die periode. Dat is volgens mij niet zo direct daar een beperking in. Dat zou je pas hebben als je naar een andere invulling van het gebouw gaat. Opdelen in kleinere units, of het veranderen van bestemming.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                          | I   | Oké                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Topic 3: Incentives and obstacles</b> |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Q3a                                      | I   | Nou, dan alweer mijn derde en laatste topic. Als eerste, jullie gaven al aan dat het nog niet heel veel gedaan wordt, dat flexibel bouwen, Welke prikkels denken jullie dat er nodig zijn om flexibiliteit meer te realiseren? Dat mensen er echt mee aan de slag gaan, of dat jullie er zelf misschien meer mee aan de slag gaan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                          | P9  | Nou ja, volgens mij is het een soort drempel, in ieder geval gevoelsmatig, dat flexibel bouwen, toekomstbestendig bouwen, duurder is. Misschien, volgens mij, is het ook wel wat duurder omdat je extra voorzieningen doet. En je zou eigenlijk op een of andere manier de eigenaar moeten uitdagen om dat wel te doen. In die zin is hoe we nu in het verleden, en nu nog steeds, al die vernieuwingen in de warmteopwekking en het installatieconcept van gebouwen versnelt hebben veranderd, is volgens mij omdat je een bepaalde score had die je nodig had om je vergunning te krijgen. Ik weet dat wij een project deden in [smaller Dutch city] waar wij een prijsvraag deden waar we een vernieuwende vorm van elektriciteitsopwekking met het water van de [waterweg]                                                                                                                                                                                                                                                                                                                              |

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|     | geprobeerd hebben. Maar dat tikt in de berekening van de EPC [Energieprestatiecoëfficiënt] heel erg lekker mee, waardoor we goed scoorde in de prijsvraagfase. Overigens is dat totaal niet van de grond gekomen omdat het water bijna stil stond. Maar in de prijsvraag hebben we erop gescoord. In de ontwikkelaar gedachte, dan zit je aan boord. Dus je zou eigenlijk een soort van prikkel moeten inbrengen dat dat bepaalde maatregelen meetellen in je, naja EPC is het volgens mij niet meer, je berekening, in de huidige bereken systematiek. De score is een plusje om makkelijker aan bepaalde eisen te voldoen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| I   | Dus het zou mee moeten worden genomen in een score die opdrachtgevers of vergunningverleners meenemen in het tenderproces?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| P9  | Ja. Want van het alleen maar de visie van marktpartijen komt heel weinig. Want je ziet dat [bedrijf waarvoor P9 en P10 werken] heeft het [gebouwnaam] gedaan [in stadsbuurt]. Maar volgens mij is daarna, maar goed dat is ook, ik werk nu iets meer dan een jaar bij [bedrijf waarvoor P9 en P10 werken], dus ik weet ook niet precies hoe alle gebouwen tussen toen en nu gebouwd zijn. Maar ik heb niet het idee dat we elk gebouw zo flexibel hebben gebouwd zoals we dat toen hebben gedaan. En het kan wel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| I   | En dat dat niet gebeurd is, is vooral een geldkwestie dan of ligt dat ergens anders aan?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| P9  | Ja. Ja, geld of geen aandacht. Het was toen gewoon een ontwikkelaar die een visie had en een opdrachtgever, in dit geval [bedrijf waarvoor P9 en P10 werken], met een directeur die daarin meeging.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| I   | Ja, dus je hebt ook iemand nodig die dat echt wil?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| P9  | Ja. Daar begint het bij. Maar als je dat wat breder in de markt zou willen leggen, dan zou je eigenlijk ook de onwillende partij een incentive kunnen geven om daarin mee te gaan. Door bijvoorbeeld zo'n scoringssysteem.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| I   | Dat je een vinkje kan zetten en trots kan zijn dat je een score behaald hebt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| P9  | Dat is heel erg meteen naar oplossingen gezocht van mij misschien.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| I   | Het is in ieder geval goed om te overwegen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| P10 | Ik zat meer te denken aan een beetje, het is natuurlijk altijd vraag en aanbod. Dus ergens zou je het ook in de markt moeten zetten ook. Als een heel aantrekkelijke vorm van vastgoed. Zodat er ook daadwerkelijk vraag komt. Kijk op het moment dat nu iedereen alleen maar nieuwbouw jaren dertig woninkjes wil kopen met een tuintje, ja dan wordt dat gebouwd want dat is wat verkoopt. En op het moment dat wij een slag kunnen maken dat dat toch flexibel, of de manier waarop wij wonen, als langzaam die markt ontwikkelt, dan denk ik dat daar ook vraag naar komt. Dat is de ene kant en aan de andere kant dacht ik aan de overheid. Wat wij heel veel zagen is dat steeds meer investeerders, zeker grote banken, die vragen steeds meer sustainability benchmark achtig iets, een GRESB [Global Real Estate Sustainability Benchmark], ESG [Environmental, Social en Governance], BREEAM [Building Research Establishment Environmental Assessment Method]. En ik denk zeker dat als je kijkt naar flexibiliteit als een vorm van duurzaamheid, dat hangt er een beetje vanaf hoe je het bekijkt. Maar dat dat dus ook een hele goeie incentive kunnen zijn. Want uiteindelijk wordt mijn vastgoed gewoon meer waard, omdat banken straks gewoon niet meer willen investeren als je geen BREEAM-label hebt. |
| P9  | Ja eens.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| P10 | Maar dat zijn nog grotere stappen dan de overheid en de EPC waren. Maar uiteindelijk, toen ik bij [vorige werkgever P10] begon toen was dat BREEAM, ja dat was maar een moetje. Dat werd dan, in London bijvoorbeeld, ben je verplicht om BREEAM very good te halen, minimaal, voor alles wat je bouwt. En op een gegeven moment zag je, na een jaar of zes, dat de banken en investeerders waar wij mee in zee gingen, begonnen ook gewoon te vragen van wij kopen niks meer, wij investeren niet meer als er geen BREEAM very good of iets dergelijks aan hangt. Nou stelt dat nog niet zo veel voor hoor, dat BREEAM very good, maar het is wel een begin. Dat gaat denk ik wel de goede kant op, zeg maar.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| P9  | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| I   | Oké, dus een stukje marketing, als je eerste punt. Als het goed in de markt gelegd wordt, dat mensen denken oja dat wil ik ook wel. En toch het een beetje meetbaar maken, scorebaar maken. Dat zijn goeie punten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

|     |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
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| Q3b | I   | Dan heb ik nog twee laatste vragen. En dat zijn een beetje de kop en staart van dezelfde vraag. Ik wil beginnen met welke kansen zien jullie voor de flexibele bouw? En dan kun je verwachten dat dus mijn volgende vraag welke obstakels is. Dus mocht je beide kanten direct willen benoemen, dan mag dat ook.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | P9  | Nou ja, ik denk dat die kansen voornamelijk liggen in de gemengde bestemmingen, op plekken waar je gemengd aan de slag wil of moet gaan. Wat je, bijvoorbeeld in [grote Nederlandse stad], er zijn in Noord allemaal van die kleine bedrijvengebouwtjes en bedrijventerreintjes aan het opruimen om maar snel woningen te kunnen bouwen. Het zou toch mooi zijn als je een soort van gemengd programma in een gebouw krijgt. Dat je onderin nog die bedrijvigheid kan hebben. Even los van dat dat misschien nog wel wat overlast veroorzaakt, omdat daar autospuiterijen enzo zitten. Maar laten we dat even parkeren. Dat je daar nog wel bedrijvigheid hebt, én wonen. En als de bedrijvigheid niet meer nodig is, dat je dan meer gaat wonen. Of als er op een gegeven moment minder wonen nodig is dat je meer kan gaan werken. Dat die gebouwen mee kunnen bewegen. En dat is denk ik eerder in een stad, dan ergens langs een snelweg. Zo zou ik het eerder zien, wat betreft locatie. En in hotels natuurlijk, [P10], als er dan minder gevlogen wordt, gaan we er gewoon permanent wonen! |
|     | P10 | Kan al, hoor, bij [vorige werkgever P10]. Je kan er al een maand wonen. Ja, daar ben ik het mee eens, locaties. En als je kijkt wat meer op een kleinere schaal, denk ik ook wel dat je het in woonwijken kwijt kan. En dan denk ik meer aan flexibel als levensbestendig. Dan kan je misschien op een gegeven moment van een rijtjeswoning, van een blok rijtjeswoningen, kan je daar misschien een appartementencomplex van maken. Bij wijze van. Op die manier flexibiliteit. Ook verschilt natuurlijk. Er is nu vergrijzing, dan komt er straks weer een golf, ja het gaat allemaal met golven. Over vijftig jaar hebben we weer een vergrijzingsgolf, maar tussendoor moeten we wel even woningen voor gezinnen hebben. Maar dat zit veel meer op een veel kleinere schaal, dat denk ik wel.                                                                                                                                                                                                                                                                                                  |
|     | P9  | Ja, maar het is ook een hele goeie inderdaad. Dat aanpasbaar bouwen, levensloopbestendig, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Q3c | I   | Goeie. Nou dan wil ik de andere kant van deze vraag opwerpen. Welke uitdagingen of obstakels zien jullie voor flexibel bouwen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P10 | Mensen moeten het willen. Ze moeten zien dat er een noodzaak is. Helaas doen heel weinig mensen iets zomaar zonder dat er een noodzaak gezien wordt. Iedereen gaat altijd keihard aan de slag de dag voor de deadline, in plaats van drie weken van tevoren. In ieder geval, zo ben ik wel, helaas. Maar dat is gewoon een beetje mens-eigen. En op het moment dat je kan in zien dat dit nodig is, dat zal een eerste stap zijn.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|     | I   | Een stukje bewustzijn?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P9  | Ja en urgentie. Er moet ergens urgentie komen. Of je dat nou moet gaan afdwingen, weet ik niet. Maar mensen moeten wel gaan voelen dat het wel belangrijk is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

Table B.13: Transcription interview P11

|                                          |                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Interviewee                              | P11                    | Policy adviser at the municipality of a large Dutch city                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Date and time                            | April 30 <sup>th</sup> | 13:30                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Topic 1: Flexibility of buildings</b> |                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Q1a                                      | I                      | Mijn eerste vraag is een beetje een inleidende vraag. Kun je mij vertellen over de ontwikkelingen in de bouw, die van interesse zijn voor jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|                                          | P11                    | Dat is een goeie vraag. Kijk, in de bouw is op dit moment sowieso van interesse, en dat is niet zo zeer technisch, maar dat het stelsel gaat wijzigen. Dat op dit moment de gemeente zelf toezicht houdt op de bouw, bij alle bouwwerken. En dat dat vanaf 1 januari, is de planning, gelijk met de invoering van de omgevingswet, de wet kwaliteitsborging voor het bouwen ingaat. En dat betekent dat een gedeelte van die taken weggaan bij de gemeente. Namelijk voor de gebouwen in de gevolklasse 1. Dat zijn niet zo hele ingewikkelde gebouwen, grondgebonden woningen, industrie functies tot maximaal twee bouwlagen, kleine kunstwerken in de openbare ruimte, kleine bruggetjes, alles voor langzaam verkeer. Daarvoor wordt de toezicht gedaan door de private kwaliteitsborger. Dat is een ontwikkeling die voor ons als gemeente van belang is en die gewoon veel betekent voor de manier waarop we |

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|     |     | georganiseerd zijn, waar we wel en niet van zijn, waar we aan toetsen. Ja en voor de rest, vernieuwende bouwtechnieken moeten altijd constructief gewoon goed in elkaar zitten. Zodat ze aan het bouwbesluit voldoen. Dus dat juichen we toe dat die er zijn en zolang dat voldoet kunnen we er gewoon mee instemmen als gemeente.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Q1b | I   | Oké. Nou dan, mijn volgende vraag is: kun je mij vertellen hoe er vanuit jouw vakgebied naar flexibel of aanpasbaar bouwen gekeken wordt?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | P11 | Ja dat antwoord heb ik eigenlijk misschien al stiekem een beetje gegeven. Zolang het voldoet aan het bouwbesluit, doen wij als gemeente niet heel moeilijk. Wij krijgen vergunningaanvragen binnen. Vervolgens hebben wij beleid waarin staat hoe wij aan vergunningaanvragen toetsen. Nou bij bouwen speelt dan de aannemelijkheidseis een rol. De vergunningaanvrager moet aannemelijk maken dat het voldoet of gaat voldoen aan de bouwregelgeving. En als dat voldoet kunnen wij de vergunning verlenen. En als het voldoet aan die bouwregelgeving, dan weten wij het constructief veilig, het is bouwveilige en het kan goed gebruikt worden. En dan is het alleen maar praktisch dat het flexibel is en dat je gemakkelijk er iets aan kunt doen op het moment dat er groot onderhoud moet gebeuren, op het moment dat er iets vervangen moet worden. Ja dat dat zonder ingrijpende maatregelen kan. Zolang dat op een veilige manier kan, zonder dat de constructie van de rest van het bouwwerk daaronder leidt, ja dan is dat prima. |
|     | I   | Dus het is vooral belangrijk dat het allemaal constructief goed in elkaar zit?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|     | P11 | Als gemeente zijn we in principe verantwoordelijk voor de handhaving van die bouwregels. Dus eigenlijk voor de veiligheid van gebouwen in de stad. Daar zit natuurlijk ook een grote verantwoordelijkheid voor de eigenaar zelf, dat die ervoor zorgt dat die aan die regelt voldoet. Maar wij zijn er om daarop toe te zien, zowel bij de bouw als daarna bij het gebruik. Dat is het belang dat we hebben. Omdat een instortend gebouw niet alleen vervelend is voor van wie dat gebouw is, maar potentieel ook voor de mensen die in dat gebouw wonen, werken, of in de omgeving van dat gebouw zijn. Als er iets instort en er dondert iets op de straat en er vallen gewonden, ja dan heb je gewoon een probleem.                                                                                                                                                                                                                                                                                                                         |
|     | I   | Precies. En naast de reglementen, hebben jullie ook nog beleid die hierbij komt kijken? Of is dat niet persé deel van de toetsing?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|     | P11 | Beleid over hoe om te gaan met duurzame of met, nee niet specifiek. Er is zoiets als wettelijk verplicht VTH-beleid. Daarin staat wat wij doen op het gebied van vergunningverlening, toezicht en handhaving. Daarin staat hoe wij toetsen en welke doelstellingen wij ons daarin stellen. Maar daarbij zijn we natuurlijk, in hoeverre die nieuwe technieken toegepast worden, ben je ook gewoon afhankelijk van die initiatiefnemers, van de mensen die een project willen starten. En je kunt als gemeente niet afdwingen, of heel moeilijk afdwingen dat mensen nieuwe technieken gebruiken.                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|     | I   | Dan zou dat echt wettelijk vast moeten liggen, dat ze dat moeten doen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|     | P11 | Als je dat wilt, als je het echt wil kunnen afdwingen in alle gevallen, dan moet het gewoon in de bouwregelgeving. Dat er technieken gebruikt worden voor, die circulariteit bevorderen. Je ziet wel steeds meer dat er bijvoorbeeld duurzaamheidseisen gesteld worden in bouwregelgeving. Dus landelijk beweegt men die kant wel op en daar toetsen we dan ook wel aan. Maar het afdwingen in een individueel geval bij een vergunningaanvraag, kan sowieso niet. Want je moet gewoon, je hebt gewoon het wettelijk kader waaraan je moet toetsen. Een omgevingsvergunning voor bouwen mag je alleen weigeren als er iets bouwkundig mis is. Dus als het niet voldoet aan de bouwregels.                                                                                                                                                                                                                                                                                                                                                      |
|     | I   | In eerdere interviews is wel eens benoemd dat als een gemeente iets heel graag wil, dat dat, bijvoorbeeld op het gebied van circulariteit, dat dat ook eerder gerealiseerd wordt door de, of in ieder geval gevraagd wordt door de opdrachtgever. Is dat een kwestie van actief meedenken, of kun je daar verder nog iets in betekenen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|     | P11 | Er zijn twee manieren waarop je er wat aan kan doen. Kijk als gemeente heb je natuurlijk ook wel eens te maken met projectontwikkelaars. Die projectontwikkelaars, als ze iets willen bouwen moeten ze een vergunning aanvragen, maar hebben ze vaak ook meer dan dat van de gemeente nodig. Bijvoorbeeld, ze moeten de grond van de gemeente kopen. Dan kom je in een sfeer van onderhandeling in het privaatrecht terecht met een anterieure overeenkomst, waar je wel degelijk ook voorwaarden kunt gaan stellen. En waar je met elkaar in onderhandeling kunt van joh zou je nou eens niet circulaire technieken toe gaan passen, als dat kan. Dat moet natuurlijk wel                                                                                                                                                                                                                                                                                                                                                                     |

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|                                       |     | <p>allemaal passen binnen die businesscase van die projectontwikkelaar. En je moet als gemeente de projectontwikkelaar ook wel iets te bieden hebben om dat af te kunnen dwingen. Voor een gemeente [gemeente waarvoor P11 werkt], is dat wat makkelijker omdat we in [gemeente waarvoor P11 werkt] polder zijn. [Gemeente waarvoor P11 werkt] bestaat nog niet zo lang. Alle niet-bebouwde grond is van de gemeente en kun je dus als gemeente uitgeven. Daar kun je dus ook privaatrechtelijk voorwaarde stellen aan het uitgeven van die grond. En als daar een projectontwikkelaar iets wil, kun je makkelijk afdwingen dat daar iets met duurzaamheid, circulariteit gebeurt. Dat die een fatsoenlijk participatietraject doorloopt met de buurt. Dat soort dingen. Dat kun je dan makkelijker afdwingen. Maar dat is in grote delen van Nederland natuurlijk veel minder het geval. Omdat dat veel ouder is, de grond daar vaak niet in eigendom van de gemeente is, maar van anderen. Als een projectontwikkelaar daar iets koopt, dan kun je als gemeente nog met een anterieure overeenkomst in onderhandeling gaan, maar dan heb je ze minder te bieden. Als zij een vergunning aanvragen en die voldoet en die past binnen het bestemmingsplan. Dat is dan vaak ook nog het probleem, dat het allemaal ruimtelijk mag. Ja dan heb je verder niet zoveel in de melk te brokkelen als gemeente, dan moet je gewoon toetsen aan wet- en regelgeving. Als dat voldoet dan krijgen ze hun vergunning.</p> |
|                                       | I   | Ja. Dus als gemeente kun je er vooral invloed op uitoefenen als je zelf echt betrokken bent bij een deel van het project, dus naast de vergunningen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                       | P11 | Precies. In die vergunningverlening zit die invloed niet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                       | I   | Dat is gewoon een checklist, als het ware.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                       | P11 | Ja, dat is gewoon een checklist. Voldoet het aan de wettelijke eisen? Voldoet de bouw aan de bouwregelgeving en zijn verder alle vergunningen die ook nodig zijn ook aangevraagd en vergunbaar? Nou dan kunnen ze gewoon starten.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Q1c                                   | I   | Duidelijk. Dan ga ik door naar mijn volgende vraag en die luidt: In mijn onderzoek definieer ik flexibiliteit, zoals ik al genoemd heb, als het vermogen van een object om aangepast te worden aan veranderende omstandigheden en eisen, zonder de noodzaak voor een ingrijpende ingreep. Nou ben ik benieuwd wat voor jou een ingrijpende ingreep zou zijn? Waar je de lijn zou trekken?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                       | P11 | Ja, vanuit het oogpunt van de gemeente zou je zeggen dat een ingrijpende ingreep is wanneer er daadwerkelijk iets aan de constructie, aan de basisconstructie van een gebouw moet worden aangepast.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|                                       | I   | En heeft dat ermee te maken dat je dan een nieuwe vergunning moet aanvragen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                       | P11 | Nou dat heeft ermee te maken dat je dan potentieel iets aan de constructie moet gaan doen, waardoor de veiligheid van het gebouw mogelijk minder wordt. En dan moet je dus in veel gevallen een vergunning aanvragen en heb je daar als gemeente een rol in, om daar iets van te vinden. Want dan gaat het echt om de veiligheid, niet alleen in dat gebouw, maar van iedereen die dat gebouw gebruikt.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                       | I   | Duidelijk antwoord.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Topic 2: Flexibility of floors</b> |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Q2a                                   | I   | Dat was mijn stukje over de algemene bouwzaken. Dan heb ik een vraag over vloeren specifiek. Ik kan me voorstellen dat dit niet helemaal binnen je vakgebied ligt, maar ik hoor graag wat je erover denkt. Hoe kan flexibiliteit van een vloer van toegevoegde waarde zijn voor jou of voor jouw vakgebied?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                                       | P11 | Ja kijk, daar moet je een verschil maken, denk ik, tussen mijn vakgebied vergunnen, toezicht en handhaven. Daar kan het denk ik van toegevoegde waarde zijn als die flexibiliteit van toepassing is, die toegepast wordt, leidt tot een wijziging die vergunning vrij is. Dus een verbouwing waar je verder geen vergunning voor nodig hebt. Waarmee wel duurzame doelstellingen behaald worden. In bredere zin voor de gemeente, denk ik dat het heel gunstig is dat dat kan. Dat die flexibiliteit er is en dat de duurzaamheidsdoelstellingen daarmee makkelijker gehaald kunnen worden. Omdat inwoners minder afval produceren bijvoorbeeld. Dan zit je wel breder dan mijn vakgebied VTH specifiek. Maar dan kijk je gewoon meer naar duurzaamheidsdoelstellingen in het algemeen van een gemeente. Minder afval in de stad, duurzamere bouwwerken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                       | I   | En als je het hebt over vergunningsvrij verbouwen, hier ben ik niet zo bekend mee, wanneer is iets vergunningsvrij?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |



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|                                          | <b>P11</b> | Daar zijn hele duidelijke eisen voor, maar dat is vrij ingewikkeld om dat precies uit te leggen. Wanneer iets, dat hangt van een aantal aspecten af. Verandert er iets constructief? Moet je bijvoorbeeld door een dragende muur heen? Je kunt je voorstellen dat je in dat geval niet vergunning vrij bent. Maar er zitten ook ruimtelijke aspecten aan. Een dakkapel op de achterkant van het huis is in heel veel gevallen vergunning vrij, want daar hebben weinig mensen last van. Aan de voorkant moet je meestal een vergunning aanvragen. Dus dat heeft met heel veel aspecten te maken. Staat in het besluit omgevingsrecht in wel een lijst van dingen die in principe vergunning vrij zijn. En als dat het niet is en het gaat om bouwen, dan is het in principe vergunning plichtig. Daar gaat straks ook wel het één en ander veranderen onder de omgevingswet. Want voor de gemiddelde woning moet je nu een vergunning aanvragen. Straks gaat voor bouwen in gevolgklassen 1, het vergunningstelsel voor het bouwtechnische gedeelte eraf. Voor het ruimtelijke gedeelte met het bestemmingsplan en straks het omgevingsplan, moet je nog wel vergunning aanvragen. Maar voor het bouwtechnische gedeelte gaat dat eraf en wordt het een melding. Daar gaan we dus ook minder doen, omdat we straks ook het toezicht voor die gevolgklasse 1 ook niet meer gaan doen. |
|                                          | <b>I</b>   | En een melding houdt dan in dat ergens in een systeem een vinkje komt te staan of?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                          | <b>P11</b> | Ja dat houdt heel concreet in dat die persoon bij ons moet melden dat ze gaan bouwen en die moet aangeven wie de kwaliteitsborger is en welk kwaliteitsborgingsinstrument die kwaliteitsborger gaat toepassen. Dan kunnen wij even kijken van joh mag deze kwaliteitsborger dit instrument toepassen en is deze kwaliteitsborger bevoegd? Heeft die een risicobeoordeling en een borgingsplan bijgevoegd? Check check, oké ga maar beginnen. En dan aan het eind van de bouw moet die nog een gereed melding doen, de initiatiefnemer. En daar moet dan een verklaring van de kwaliteitsborger bij zitten, dat er gebouwd is volgens de bouwregels. Ontbreekt dat, dan kun je daartegen optreden als gemeente.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Topic 3: Incentives and obstacles</b> |            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Q3a</b>                               | <b>I</b>   | Oké. Nou mijn derde deel is dus prikkels, kansen en uitdagingen. En de eerste vraag daarbij is: welke prikkels denk jij dat er nodig zijn om flexibele bouw te realiseren, of dat het opgenomen wordt in investeringen of ander beleid?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                          | <b>P11</b> | Ik denk, wat er aan prikkels nodig is. Als gemeente kun je bij grote projecten, waar je als gemeente zelf een rol in hebt, kun je wel het één en ander doen. Dat is beperkt, maar je kunt wel het één en ander. Als jij een groot project wil gaan doen rondom duurzaamheid of je wil een evenement organiseren rondom duurzaamheid, waar ook op een gegeven moment gebouwen komen te staan, nou dan kun je daar echt wel eisen aan gaan stellen, als de grond van jou is. Is dat nou niet het geval en heb je het meer over de grote ontwikkelingen als in, we gaan een woonwijk bouwen, dan is dat veel ingewikkelder. Als daar iets voldoet aan de huidige bouwregelgeving, dan moeten wij het gewoon toetsen. Dus wat je dan aan prikkels nodig hebt om het te stimuleren is dat het landelijk in regelgeving terecht komt dat het zo gebouwd moet worden.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                          | <b>I</b>   | Dus het opnemen in regelgeving.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                          | <b>P11</b> | Dan moet het echt landelijk. En daar kun je voor gaan lobbyen als gemeente, maar daar sta je in je eentje als gemeente nooit sterk voor. Dan moet je dat met Bouwend Nederland, overkoepelende organisaties voor bouwbedrijven, gaan doen of naar de vereniging Nederlandse gemeenten. Dan kun je wel druk uitoefenen op de tweede kamer of daar iets van te vinden, of op het ministerie die voor die regelgeving verantwoordelijk is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                          | <b>I</b>   | En vanuit andere gesprekken rondom mijn afstuderen heb ik ook wel eens het woord subsidies horen vallen. Is dat ook iets wat de gemeente kan doen?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                          | <b>P11</b> | Dat kan, hè. De gemeente die mag gewoon subsidies vertrekken voor van alles en nog wat. Dat kun je ook doen op het gebied van duurzaam bouwen. De vraag is wel, hoe realistisch is dat? Als je kijkt naar de gemeentefinanciën en de berichten die je daarover in de media misschien ook wel hoort op dit moment. Veel gemeenten zitten gewoon met een gigantisch tekort vanuit het sociaal domein. Dus die moeten al op van alles bezuinigen. Er gaan eerder voorzieningen weg, dan dat erbij komt. Er wordt ook op cultuur subsidies veel bezuinigd. Nou daar komt dan straks de omgevingswet en de BKB nog bij. Daar zitten ook verborgen invoeringskosten aan, die de gemeenten                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |



|     |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     |     | moeten gaan dragen. Dus, ja in principe kan het wel als het geld er is, maar het geld is er niet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|     | I   | Nee, precies. Dus het is theoretisch een mogelijkheid, maar in praktijk is dat lastig.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | P11 | Bij ongelimiteerde middelen, ja absoluut. Dan is subsidie een goede optie. En het is ook niet uit te sluiten dat sommige gemeentes het wel doen, hè. Als er na de gemeenteraadsverkiezing een college zit dat een redelijk duurzame, linkse inslag heeft. Ja dan kan het best zijn dat een gemeente zegt dat ze daar subsidies voor gaan geven. Maar, ja dat blijft altijd een afweging in het grotere geheel van de gemeentefinanciën. En die zijn bij heel veel gemeentes op dit moment niet zo gunstig.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|     | I   | Dat is een krappe puzzel.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P11 | Dat wordt heel ingewikkeld, ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|     | I   | Ja, snap ik.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Q3b | I   | Nou dan heb ik nog twee laatste vragen, die allebei, het is eigenlijk een tweeluik van vragen. De eerste vraag is: welke kansen zie je voor flexibele bouw? En dan zie je natuurlijk aankomen dat mijn laatste vraag juist over de obstakels voor de flexibele bouw gaat. Maar ik wil graag beginnen met de kansen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|     | P11 | Ja ik denk dat flexibele bouw op zich kansrijk is om te voldoen aan duurzaamheidsdoelstellingen. Op het moment dat jij dus zonder onmiddellijk sloopafval te creëren toch, nou bijvoorbeeld, een systeem in een vloer wat bijvoorbeeld verwarming is, kunt vervangen, ja dan draag je daarmee bij en alle kleine steentjes helpen. Gaat het nou heel veel gewicht in de schaal leggen? Nou waarschijnlijk niet het meest. Circulariteit is belangrijk en hergebruik, maar het is vervolgens ook wat gebeurt er in de rest van de keten mee? En ik denk wat dat betreft dat de energietransitie naar met nul op de meter bij woningen, zonnepanelen erop, goed isoleren, dat dat meer effect gaat hebben. Maar ik denk zeker wel dat het bij kan dragen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I   | De kansen liggen vooral in het bijdragen aan de duurzaamheid.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|     | P11 | Ja.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Q3c | I   | Oké, nou dan de andere kant van deze vraag: welke uitdagingen of obstakels voorzie je met betrekking tot flexibele bouw?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P11 | Ja de obstakels vanuit mijn vakgebied, die zitten er vooral in als er flexibel gebouwd moet worden en vervangen moet worden en dat op dit moment niet in overeenstemming zou zijn met de bouwregels. Als de oplossing die opgedragen wordt, ook al is die heel erg duurzaam, op dit moment niet automatisch past binnen de bouwregels. Dan is er wel een uitweg, dan moet je gelijkwaardigheid gaan aantonen, zoals dat dan heet. Dan moet je gaan aantonen dat, ook al voldoet het niet sec aan de regels, hetzelfde beschermingsniveau van veiligheid, constructief dan wel brandveiligheid dan wel bijdragen aan gezondheidsdoelstellingen, gezondheidseisen die er aan een woning, of de bruikbaarheidseisen die er aan een woning gesteld worden. Dat het daaraan voldoet. En dan moet je gelijkwaardigheid gaan aantonen. En dat moet dan in het geval van een constructie een constructeur naar gaan kijken en in geval van brandveiligheid, een brandveiligheidsexpert. En dan moet je gewoon in de vergunning opnemen dat er een gelijkwaardige oplossing gekozen is. Maar dat is vaak veel werk en kost tijd en dat moet ook kunnen. Is het echt niet te rijmen met de bouwregelgeving? Ja dan ga je er gewoon een vergunningaanvraag op weigeren. |
|     | I   | Ja, een object moet natuurlijk gewoon altijd voldoen aan de regelgeving.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|     | P11 | Precies, dat is vanuit mijn vakgebied het belangrijkste. Mm te kunnen garanderen dat het gebouw veilig is als het gebouwd wordt, veilig is voor de mensen die dat gebouw gaan gebruik en veilig is voor de omgeving. En dat is gedurende een periode van een x aantal jaar. Want op dit moment zijn de eisen aan het bouwbesluit zo dat je er dan vanuit kunt gaan dat het dan 50 jaar veilig is nadat het gebouwd is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|     | I   | En is het iets, ik wilde zeggen 'vaak' maar dat lijkt me wat overdreven, tegenkomt in je werk, dat er een element of een constructiedeel opgenomen is waarvan je denkt...                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|     | P11 | Daar zit ik zelf dan onvoldoende in. Ik ben beleidsadviseur, dus ik maak het beleid eromheen. En ik behandel zelf geen vergunningaanvragen. Dus dan zou je echt met een vergunningverlener of een constructeur om tafel moeten om te kijken van joh hoe vaak kom je nou dingen tegen waarvan je denkt hmmm. Maar dat kan van alles zijn, hè. Als je het bouwbesluit doorloopt, het is zo gek of er bestaan regels voor.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|     | I   | Dat heb ik wel eens gezien ja!                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

|                              |            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | <b>P11</b> | Ik bedoel, je studeert zelf in die hoek, dus dan weet je wat voor eisen er aan allerlei verschillende constructies en bouwwerken gesteld worden.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|                              | <b>I</b>   | Ja, ja dat klopt. Dat is soms redelijk specifiek.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                              | <b>P11</b> | Precies.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Discussion afterwards</b> |            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                              | <b>I</b>   | Een aantal keer was benoemd dat mensen zeiden dat dit getrokken moet worden door bijvoorbeeld de gemeente. Ik heb nu wel het idee dat dat niet helemaal realistisch is.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                              | <b>P11</b> | Nou ja, kijk de gemeente kan alleen iets op het moment dat er spraken is van projectontwikkeling waar ze zelf bij betrokken zijn. En je kunt er allerlei beleid voor gaan opstellen en dat gaan stimuleren en in duurzaamheidsvisies en dat soort dingen allemaal vastleggen dat je voor duurzame en circulaire bouw bent, maar je kunt het zelf zo moeilijk afdwingen, omdat je zelf zo weinig bouwt. Als gemeente bouw je ook wel het één en ander aan bouwwerken en je hebt ook wel het één en ander in beheer, zeker als grotere stad. Maar je bent uiteindelijk toch afhankelijk wat initiatiefnemers daarmee willen. Je kunt initiatiefnemers op allerlei manieren stimuleren om dat te doen. Door het in een beleid op te nemen of door subsidies te geven, daarvoor moet dan wel het geld zijn. Maar als je het echt wil afdwingen, dan moet het gewoon vanuit de landelijke overheid komen en dan moet je er gewoon bouweisen van maken. |
|                              | <b>I</b>   | Ja, dat is duidelijk denk ik. Daar kan ik zelf natuurlijk niet zoveel mee in mijn thesis, maar ik vind het wel belangrijk om het te benoemen.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

## Appendix C Literature study existing solutions

### C.1 Approach

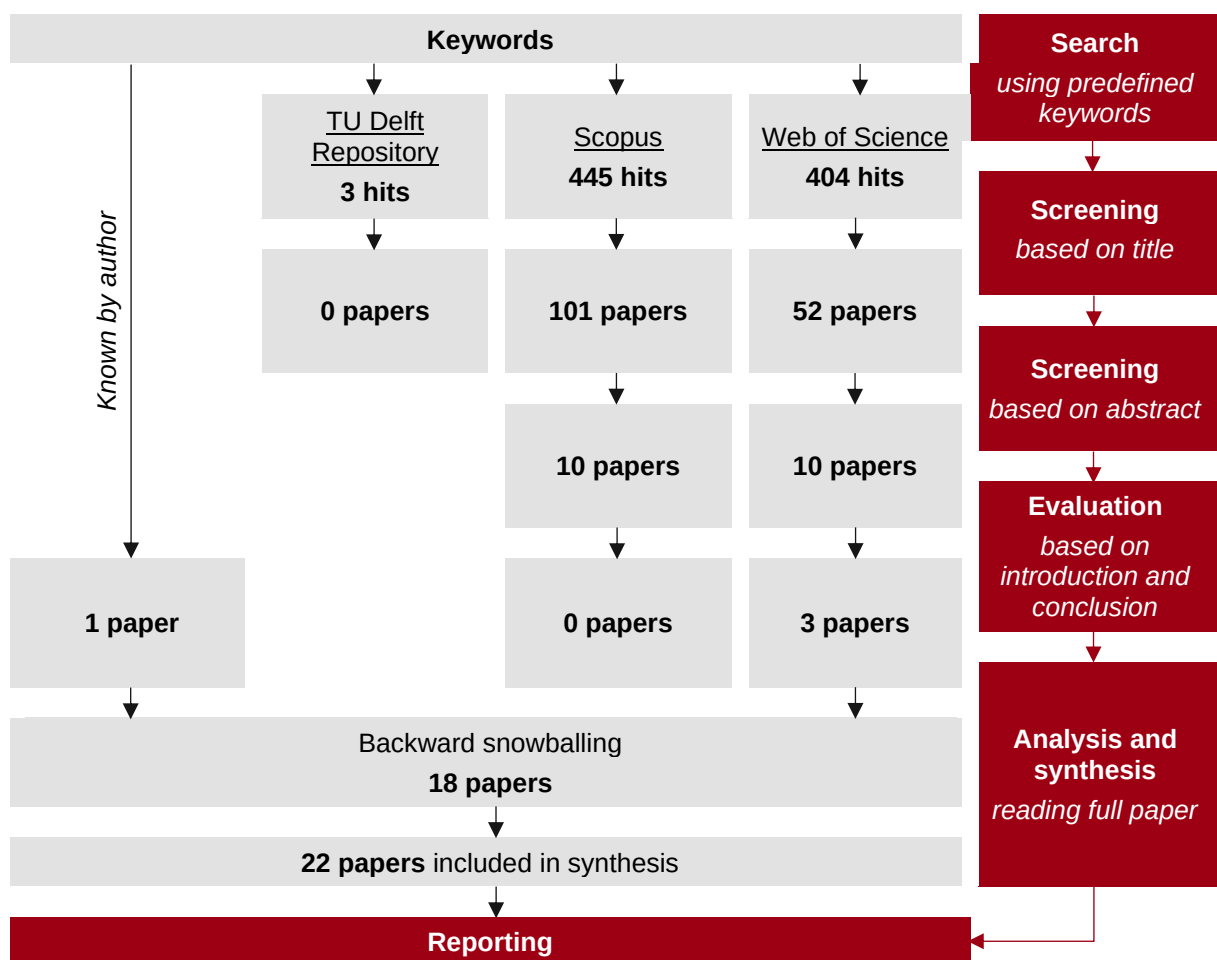


Figure C.1: Steps taken in literature review research question 2

Table C.1: Keywords for search term research question 2

|                                                                             |     |                         |     |                                                                  |
|-----------------------------------------------------------------------------|-----|-------------------------|-----|------------------------------------------------------------------|
| Flexib*<br>Flexibility<br>Flexible<br>Adaptab*<br>Adaptability<br>Adaptable | AND | Floors<br>Floor systems | AND | Building<br>Structur*<br>Structure<br>Structural<br>Construction |
|-----------------------------------------------------------------------------|-----|-------------------------|-----|------------------------------------------------------------------|

Figure C.1 shows the steps taken in the initial review of the literature and Table C.1 gives the keywords used to formulate the search term. The results of this literature study almost exclusively regarded floor systems with integrated building services. To expand on these results, an additional literature review was done on floor systems where the building services are placed on top or below the floor structure. The research process and search terms used are outlined in Figure C.2 and Table C.2 respectively.

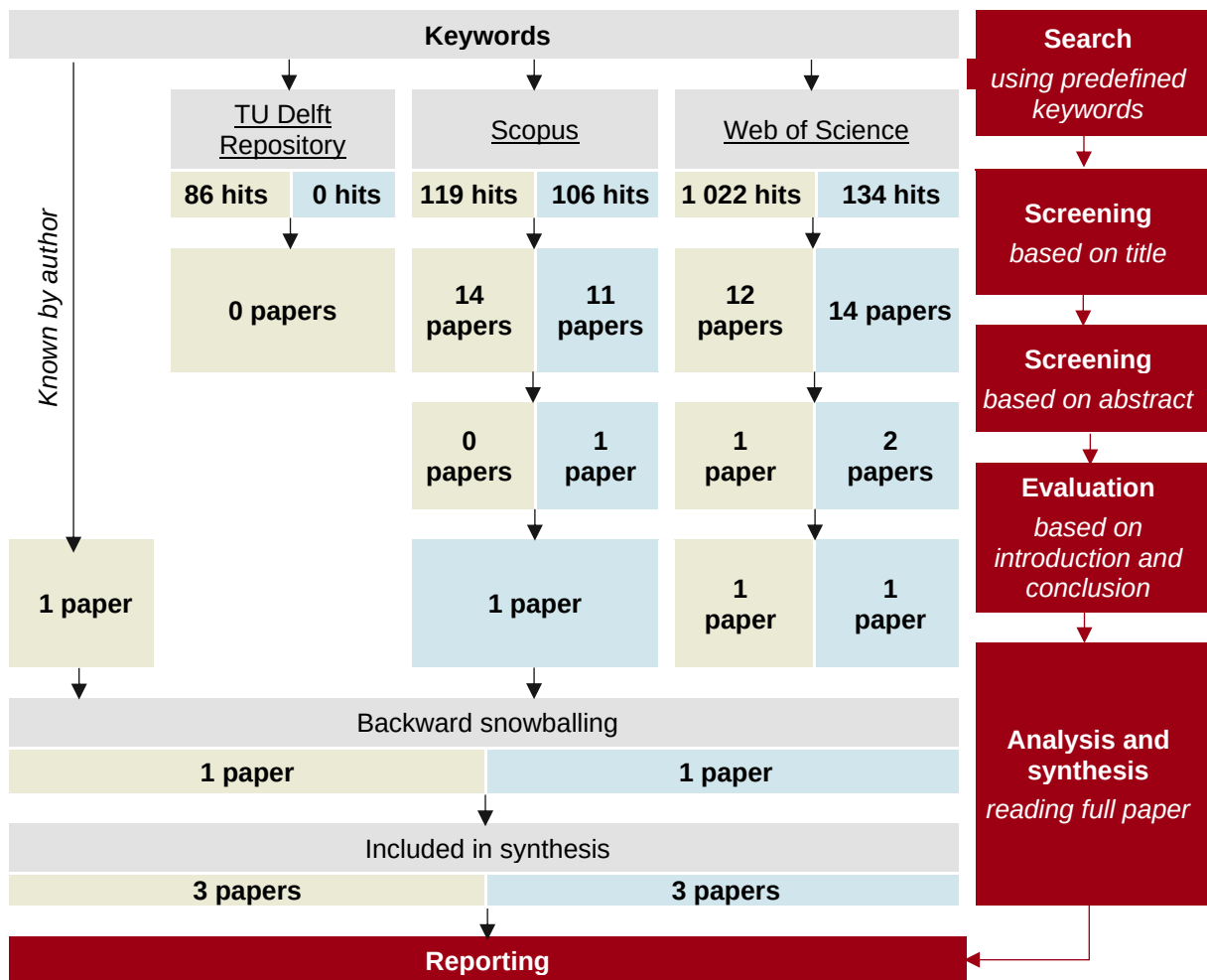


Figure C.2: Steps taken in expanded literature review research question 2

Table C.2: Keywords for search terms expanded literature review research question 2

|                              |     |                         |     |                                       |     |         |
|------------------------------|-----|-------------------------|-----|---------------------------------------|-----|---------|
| Raised<br>Computer<br>Access | AND | Floors<br>Floor systems | AND | Suspended<br>Drop*<br>Drop<br>Dropped | AND | Ceiling |
|------------------------------|-----|-------------------------|-----|---------------------------------------|-----|---------|



### Included

- Article
- Conference paper
- Review
- Report
- Business article

### Excluded

- Abstract report
- Book and book chapter
- Data paper
- Editorial
- Erratum
- Letter
- Note
- Retracted article
- Short survey
- Undefined

### **Limiting subject areas**

Certain subject areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain subject areas is outlined below.

- Subject areas unrelated to floor design

*Excluded subject areas: Computer science, Medicine, Chemistry, Physics and astronomy, Social sciences, Biochemistry, genetics and molecular biology, Agricultural and biological sciences, Energy, Earth and planetary science, Chemical engineering, Business, management and accounting, Psychology, Neuroscience, Arts & humanities, Economics, econometrics and finance, Immunology and microbiology, Health professions, Nursing, Dentistry, Veterinary, Decision sciences, and Pharmacology, toxicology, pharmaceuticals.*

### **Limiting and excluding keywords**

First, the search results were limited to keywords essential to the search term. For the first research round these keywords were *Floors* and *Flexible structures* and for the second research round only *Floors*. Then, a number of keywords were excluded from the remaining search results. The reasoning for excluding certain keywords is outlined below.

- Keywords that indicate a different interpretation of the search term than intended

*Excluded keywords: Elasticity, Stiffness, Suspension (fluid)*

- Keywords that indicate modelling or in-depth analysis

*Excluded keywords: Mathematical models, Finite element method, Vibration control, Structural dynamics, Damping, Dynamics, Seismology, Modal analysis, Robustness, Earthquakes, Dynamic response, Vibration analysis, Numerical methods, Seismic design, Natural frequencies, Fires, Seismic response heating, Vibration, Parameter estimation, Vibration suppression, Frequency response, Dynamic loads, Floor vibrations, Nonlinear equations, Eigenvalues and eigenfunctions, Fire resistance, Frequency domain analysis, Uncertainty analysis, Numerical analysis, Numerical model, Iterative methods, Genetic algorithms, Numerical models, Computer software, Differential equations, Dynamic analysis, Earthquake resistance, Sensitivity analysis, Vibration serviceability, Earthquake engineering, Seismic performance, Failure analysis, Cracks, Reinforcement, Shrinkage, Computer aided design, Models, Non-destructive examination, Vibrations, Computer simulation, Numerical simulation, Optimization, Three dimensional computer graphics, Computer aided engineering, Finite element analysis, Numerical investigations, Computational methods, Computer modelling, Testing, Experiments, Flammability testing, Shake table tests, Experimental investigations, and Earthquake simulator.*

- Keywords that are not directly related to floor design

*Excluded keywords: Algorithms, Controllers, Tall buildings, Sensors, Control systems, Control system synthesis, Control theory, Feedback control, Manufacture, Energy utilization, Manipulators, Energy efficiency, Optimal control systems, Robotics, Computational fluid dynamics, Aerodynamics, Robots, Identification (control systems), Roofs, Robust control, Adaptive control systems, Atrix, Flexible manipulators, Control system analysis, Spacecraft, Fluid structure interaction, Motion control, Friction, Columns (structural), Errors, Energy dissipation, Active vibration controls, Costs, Closed loop control systems, Control equipment, Energy conservation, Piezoelectric actuators, Feedback, Position control, Nonlinear control systems, Piezoelectricity, Distributed parameter control systems, Forecasting, Automation, Heat transfer, High rise buildings, Neural networks, Air, Elevators, Transfer functions, Error floor, Space applications, Energy conservation, Satellites, Progressive collapse, State space*

methods, Time domain analysis, Walls (structural partitions), Project management, Maintenance, Repair, Mortar, Bridges, Accident prevention, Intelligent buildings, Cost-effectiveness, Decision making, Durability, MEMS, Retrofitting, Digital storage, Quality control,, Moisture, Glass, Monte Carlo Methods, Railroads, Soils, Substrates, Surveys, Aerospace engineering, Aircraft bridge decks, Wireless telecommunication systems, Antennas, Pavements, Carbon dioxide, Flexible electronics, Aircraft, Control tower, Vehicles, Machine design, Turbulence, Drag, Lighting, Machinery, Offshore structures, Wheels, Antenna phased arrays approximation theory, Automobile bodies, Coal deposits, Diesel engines, Electric impedance, Fabrication, Flexible spacecraft, Fluid dynamics, Hamiltonians, Internet of Things, Interplanetary flight, Data centers, Computer control systems, Article, Atmospheric temperature, Data acquisition, Monitoring, Scheduling, Data center, Planning, Turbulence models, Computer aided manufacturing, Machine tools, Application programs, CFD, Codes (symbols), Computer vision, Data processing, Human, Humans, Location, Process control, Solar energy, Visualisation, Reynolds number, Pressure drop, Nozzles, Tunnels, Actuators, Fans, Fuels, Hose, Losses, Seismic waves, Sprinkler systems (irrigation), Aerosols, Climatic chamber, Drop formation, Fighter aircraft, Geophysics, Priority journal, Radiant panel, Thermal plumes, Water sprays, Adsorption, Animal, Animals, Atomization, Combustion, Contamination, Exhibitions, Flow of fluids, Flow rate, and Flow visualization

### Limiting source titles

Finally, certain source titles were excluded based on whether their subject area is related to floor design. Excluded source titles: *Proceedings of the IEEE Conference on Decision and Control*, *Proceedings of the American Control Conference*, *Energy and buildings*, *Acta Astronautica*, *Journal of Microelectromechanical systems*, *IEEE International Symposium on Personal Indoor and Mobile Radio Communications RIMRC*, *IEEE Transactions on Communication*, *IEEE Transactions on Vehicular Technology*, *IEEE Wireless Communications and Networking Conference WCNC*, *Journal of Aircraft*, *Asia Pacific Microwave Conference Proceedings APMC*, *IEEE Journal of Solid State Circuits*, *Journal of Bridge Engineering*, *AIAA Guidance Navigation and Control Conference and Exhibit*, *American Society of Mechanical Engineers pressure vessels and piping division publication PVP Annals of Biomedical Engineering*, *IEEE Transactions on Antennas and Propagation*, *IEEE Transaction on Control Systems Technology*, *Proceedings of IEEE Sensors*, *Transportation Research Record*, *IECON Proceedings Industrial Electronica Conference*, *IEEE International Symposium on Industrial Electronics*, *Icmphpc 2010 International Conference on mine hazards prevention and control*, *Proceedings IEEE international symposium on circuits and systems*, *Fisita World Automotive Congress 2018*, *IEEE Antennas and wireless propagation letters*, *Journal of Offshore Mechanics and Arctic Engineering*, *SAE International Journal of Passenger Cars Mechanical Systems*, *3<sup>rd</sup> International Fib Congress and Exhibition Incorporating the PCI Annual Convention and Bridge Conference Think Globally Build Locally Proceedings*, *Advances in Radio Science*, *Conference Record of the IEEE Photovoltaic Specialists conference*, *Globecom IEEE Global Telecommunications Conference*, *Guidance Navigation and Control Conference 1994*, *IEEE National Radar Conference Proceedings*, *IEEE Transactions on Circuits and Systems II Express Briefs*, *IEEE Transactions in Industrial Electronics*, *IEEE Wireless Communications Letters*, *International journal of machine tools and manufacture*, *Journal of fluids engineering transactions of the ASME*, *Journal of Mechanisms and Robotics*, *Micromachines*, *Physical communication*, *Proceedings IEEE Military Communications Conference MILCOM*, *Proceedings IEEE Virtual Reality*, *Proceedings of the custom integrated circuits conference*, *Proceedings of the international symposium on the physical and failure analysis of integrated circuits IFA*, *Elevator world*, *Nonlinear dynamics*, *Automatica*, *8<sup>th</sup> Mediterranean conference on control and automation MED 10 conference proceedings*, *2013 international conference on manipulation manufacturing and measurement on the nanoscale 3 m nano 2013conference proceedings*, *Aerospace science and technology*, *Applied engineering in agriculture*, *Australian coasts and ports 2019 conference*, *Bridge structures*, *Bulk solids handling*, *Canadian Biosystems Engineering Le genie des Biosystems Au Canada*, *USDA Forest Service Research Paper FPI Forest Products Laboratory*, and *2011 Int Quantum Electron Conf IQEC 2011 and Conf Lasers and Electro Optics CLEA Pacific Rim 2011 Incorporating the Australasian Conf Optics Lasers and Spectroscopy and the Australian Conf*.



## C.2.2 TU Delft Repository

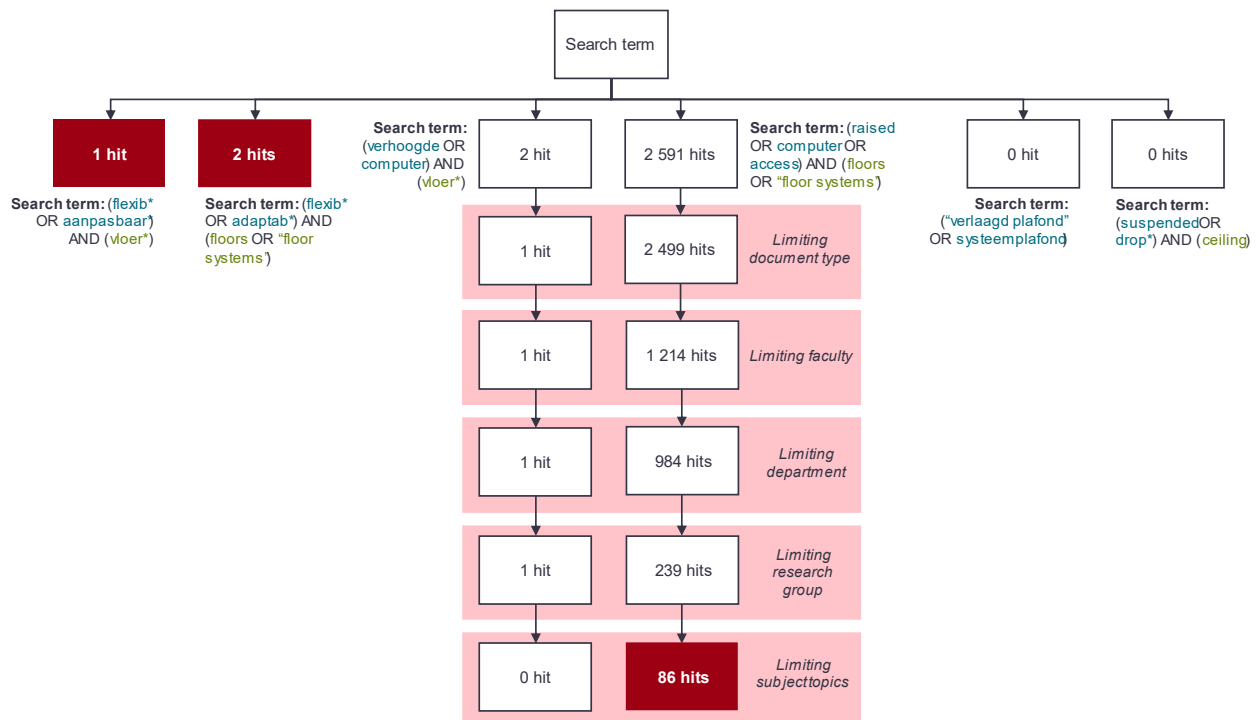


Figure C.4: Flow chart of filters applied to search term TU Delft Repository research question 2

As shown in Figure C.4, the search terms are put into the TU Delft Repository both in Dutch and in English. When this yielded only a limited number of search results, no further filters were applied.

### Limiting document type

The selection applied to the search results of the TU Delft Repository is similar to that of the search results of Scopus, with the addition of doctoral theses.

#### Included

- Doctoral thesis
- Conference paper
- Journal article
- Report
- Review
- Contribution to periodical

#### Excluded

- Abstract
- Book
- Book chapter
- Lecture notes
- Patents
- Poster
- Other (PowerPoint presentations)

### Limiting faculty

Research from certain faculties was excluded because they lack relation to floor design.

*Excluded faculties: Aerospace engineering, Electrical engineering, mathematics and computer science, Industrial design engineering, Information systems and technology, information technology and systems, Mechanical maritime and Materials engineering, OTB research institute, OTB research institute for the built environment, QuTech, and Technology, policy and management.*

### Limiting department

In addition to faculties, also departments that are unrelated to floor design are excluded.

*Excluded departments: Aerospace structures & materials, Applied physics, Biotechnology, Bionanoscience, Biotechnology, Chemical Engineering, Control & operations, Delft center for systems and control, Delft centre for entrepreneurship, DelftChemTech, Electrical sustainable energy, Engineering, systems and services, Executive board, Geoscience & engineering, Geoscience & remote sensing, Geotechnology, Hydraulic engineering, Imaging science & technology, Industrial design, Intelligent systems, Kavli institute of nanoscience, Kluysver centre for genomics, Management in the built*

environment, Multi actor systems, Multi scale physics, OTB, Precision and microsystems engineering, Process and Energy, Quantum nanoscience, Quantitative imaging group, Quantum & computer engineering, Radiation, radionuclides and reactors, Radiation, science and technology, Software technology, Space engineering, Transport & planning, Urbanism, Values technology and innovation, Water management, Water resources management.

### **Limiting research group**

Also research groups that are not related to floor design are excluded.

*Excluded research groups: MSE, 3D Geo-information, Aerodynamics, Aerospace structures & computational mechanics, Aerospace transport & operations, Aircraft noise and climate effects, Algorithmics, Applied ergonomics and design, Applied quantum architectures, Atmospheric remote sensing, Biomechanics & human-machine control, Bionanoscience, Biotechnology, Chemical engineering, Circuits and systems, Coastal engineering, Computer graphics & visualisation, Complex fluid processing, Computer engineering, Control & simulation, Cyber security, Cyber-physical systems, Data-driven control, DC system, energy conversion & storage, Design informatics, DiCarlo lab, Distributed systems, Economics of technology and innovation, Education and research support, EKL equipment, Electronic components, technology and materials, Electronic instrumentation, Embedded and networked systems, Emerging materials, Energy & industry, Energy technology, Engineering thermodynamics, , Environmental fluid mechanics, Environmental technology and design, Ethics & philosophy and design, Flight performance and propulsion, Fluid mechanics, FTQC/Charbon lab, Geo information, Geo-engineering, GIS technology, Hansson lab, Health, safety and environment, heritage & design, History & complexity, Human information communication design, Human-robot interaction, Hybrid, adaptive and nonlinear, Hydraulic, structures and flood risk, ImPhys, Information and communication technology, Integral design and management, intelligent electrical power grids, , Intelligent vehicles & cognitive robotics, Intensified reaction and separation systems, Interactive intelligence, Internet of Things, Landscape architecture, Learning & autonomous control, Marketing and consumer research, Mathematical geodesy and positioning, Mathematical physics, Mechatronic design, Mechatronic systems design, Medical instruments & bioinspired technology, Microwave sensing, signals & systems, Multi phase systems, Multimedia computing, Network architectures and services, Networked cyber-physical systems, Novel Aerospace materials, Numerical analysis, Numerics for control & identification, Optical and laser remote sensing, Optimization, Organisation and governance, Pattern recognition and bioinformatics, Petroleum engineering, Policy analysis, Programming languages, QCD, QID, QN, Railway engineering, Resource engineering, Robot dynamics, RST, Safety and security science, Sanitary engineering, Ship design, production and operations, Ship hydromechanics and structures, Software engineering, Space systems engineering, Spatial planning and strategy, Support human-centered design, Tera-hertz sensing, Transport and logistics, Transport and planning, Transport engineering and logistics, Urban studies, Vandersypen lab, Water resources, Web information systems, Wind energy.*

### **Limiting subject topics**

Finally, subject keywords were excluded from the research when they were unrelated to floor design.

*Excluded subjects: Cadastral systems, Asteroid mining, Washing machines, Cellular components, Internet of things, Additive manufacturing, Air traffic control, Aircraft, Computational fluid dynamics, Alkalinity, Computer systems performance, Artificial intelligence, Atmospheric turbulence, Satellite orientation, Australia, Autonomous vehicle, Sensor fault detection, Aerial photographs, Microstructure, Bridges, Fluid structure interaction, Signal processing, Poverty, Capillary absorption of water, Glass, Nanoindenter, Airborne laser scanning, Dancing, Consumer behaviour, Data, Sequence mining, Erosion, Nanotechnology, Computer simulation, Particle dispersion, Costs, Satellite systems, Deflation, Atmospheric turbulence, Slump test, Dufflow, Virtual coach, Human-computer interaction, Electromagnetic interference, Emotion curve, Infrastructure, Police, Fever diagnostics, Manufacturing systems, Flight test instruments, Form-finding, Labour, Land, Mathematical models, Microwave landing systems, Molecular simulation, Nigeria, Command language, Ontology, Photovoltaics, Quantum noise, Range imaging, Robotics, Software engineering, Supramolecular polymers, Urban planning, Waves, Wind.*

### C.2.3 Web of Science

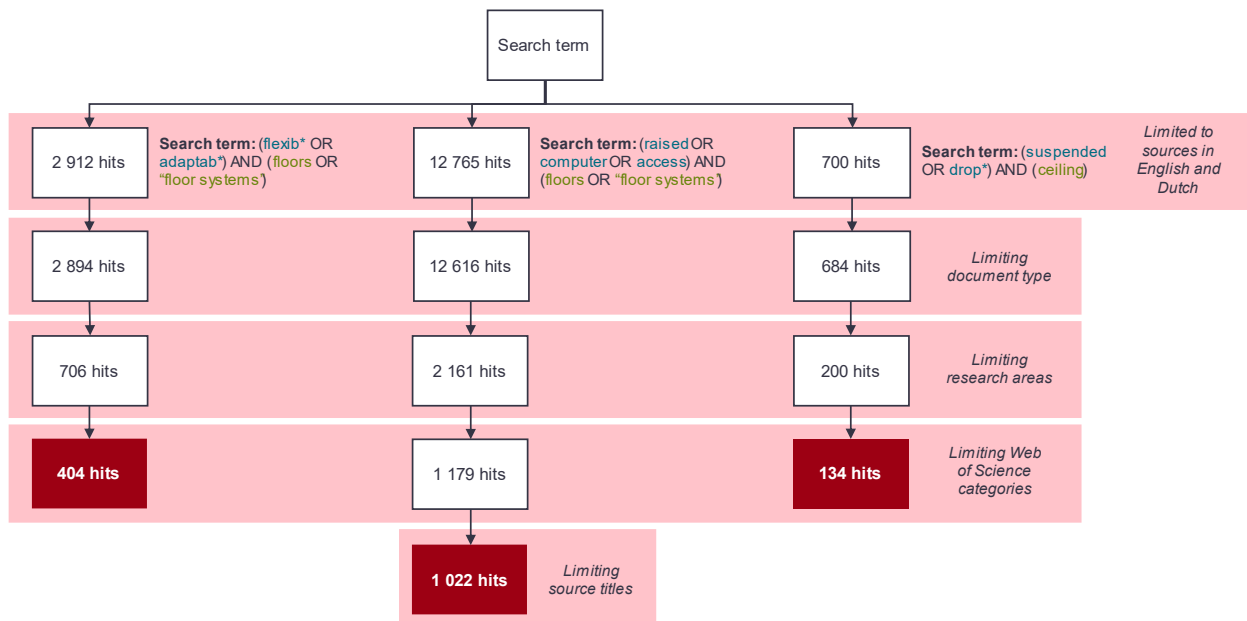


Figure C.5: Flow chart of filters applied to search term Web of Science research question 2

The search term for Web of Science is set to search in Topic, which includes the title, abstract, author keywords, and Keywords Plus. The initial results are directly filtered to only include sources in Dutch and English.

#### Limiting document type

The document types selected are comparable to those selected for Scopus.

##### Included

- Article
- Proceedings paper
- Review
- Early access article
- Reprinted article

##### Excluded

- Editorial material
- Note
- Letter
- Book chapter
- Retracted publication
- Data paper
- Correction
- Book review
- Meeting abstract
- Software review
- Book

#### Limiting research areas

Certain research areas are excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain research areas is outlined below.

- Subject areas unrelated to floor design

*Excluded subject areas: Public administration, Geography, Computer science, Public environmental occupational health, Nursing, Dentistry oral surgery medicine, Paediatrics, Automation control systems, Oceanography, Physical geography, Operations research management science, Forestry, Research experimental medicine, General internal medicine, Rheumatology, Telecommunications, Metallurgy Metallurgical Engineering, Sociology, Business economics, Psychology, Biotechnology applied microbiology, Robotics, Radiology nuclear medicine medical imaging, Mathematical methods in social sciences, Energy fuels, Health care sciences services, Physiology, Environmental Sciences ecology, Otorhinolaryngology, Anatomy*

morphology, Science technology other topics, Polymer science, Audiology speech language pathology, Instruments instrumentation, Remote sensing, Cell biology, Physics, Urology nephrology, Emergency medicine, Geology, Veterinary sciences, Endocrinology metabolism, Water resources, Evolutionary biology, Optics, Nuclear Science Technology, Food science technology, Neurosciences neurology, Pharmacology pharmacy, Immunology, Zoology, Integrative complementary medicine, Surgery, Behavioral sciences, Medical informatics, Rehabilitation, Marine freshwater biology, Plant sciences, Sport sciences, Social sciences other topics, Toxicology, Agriculture, Astronomy astrophysics, Biophysics, Chemistry, Geochemistry geophysics, Entomology, Orthopaedics, Life sciences biomedicine other topics, Fisheries, Meteorology atmospheric sciences, Government law, Urban studies, Obstetrics gynaecology, Infectious diseases, Education Educational research, Palaeontology, Linguistics, Anthropology, Women's studies, Thermodynamics, Information science library science, Anaesthesiology, Transportation, Mining mineral processing, Area studies, Geriatrics gerontology, Oncology, Arts humanities and other topics, Image science photographic technology, Archaeology, Cardiovascular system cardiology, Biochemistry molecular biology, Developmental biology, Mineralogy, Ophthalmology, Gastroenterology hepatology, Biodiversity conservation, Parasitology, Microbiology, Psychiatry, Genetic heredity, Tropical medicine, Pathology, Legal medicine, Substance abuse. Art, Family studies, Respiratory systems, Classics, Demography, Electrochemistry, Genetics heredity, History, Mathematical computational biology, Medical laboratory technology, and Music.

### Limiting Web of Science categories

All sources covered by the Web of Science core collection are also assigned a subject category. These categories are similar to the research areas but can still provide the next level of filtering.

#### - Subject areas unrelated to floor design

*Excluded subject areas: Engineering geological, Engineering electrical electronic, Engineering manufacturing, Engineering industrial, Engineering biomedical, Engineering environmental, Engineering aerospace, Ergonomics, Mathematics interdisciplinary applications, Engineering ocean, Engineering marine, Engineering chemical, Gastroenterology hepatology, International relations, Statistics probability, Communication, Developmental biology, Engineering petroleum, Genetics heredity, History, Mathematical computational biology, Mathematics, Medical laboratory technology, Microbiology, Nutrition dietetics, Philosophy, Social issues, Transplantation, Virology, Materials science characterization testing Humanities multidisciplinary, Art, Fisheries, Anesthesiology, Medical legal, Rheumatology Sociology, Substance abuse, Area studies, Dermatology, Religion, Development studies, History philosophy of science, Respiratory system, Social work, Toxicology, Asian studies, Cultural studies, Dance, Family studies, Integrative complementary medicine, Literature, Material science textiles, Music, Mycology, Women's studies, Allergy, Criminology penology, Electrochemistry, Film radio television, Literature romance, Medieval renaissance studies, Social sciences mathematical methods, Theater, Materials science paper wood, and Operations research management science*

### Limiting source titles

To limit the number of hits further, the source titles are filtered based on their relevance to floor design.

*Excluded source titles: Automation in construction, Fire technology, Fire and materials, Journal of wind engineering and industrial aerodynamics, Tunnelling and underground space technology 9th Asia Oceania symposium on fire science and technology, Thin walled structures, Materials, Shock and vibration, Wind and structures, Journal of fire protection engineering, Journal of pressure vessel technology transaction of the ASME, WIT transactions on the built environment, Forensic engineering 2018 forging forensic frontiers, and Journal of vibration and control.*

## C.3 Screening

The screening of all the sources found was done in two phases. First, all of the hits were screened based on their title. Then, a second screening took place based on the abstracts of the remaining sources. In some cases, sources were also excluded because the full article was not available through either open access or TU Delft resources.

### Screening based on title

Based on the title, certain hits were excluded according to the following criteria.

- Difference in scale  
This research regards flexibility at a (building)component level. Certain hits were excluded because their titles indicate that their scope at a significantly different scale.
- Different interpretation of search term than intended  
Hits were excluded when their title indicates a different interpretation of certain search term keywords than intended.
- Subject areas unrelated to floor design  
Hits were excluded when their title indicates a subject area unrelated to floor design.

### Screening based on abstract

Hits were included in the first search round if the abstract contains mention of or reference to flexibility and floors. For the second search round, a mention of a structure on top or below the floor was required.

## C.4 Evaluation

Further evaluation of the search hits for the inclusion in the literature study is done based on the introduction and conclusion. The criteria for inclusion is similar to that of the screening based on the abstract. In some cases, no conclusive judgement could be made based on the introduction and conclusion of the paper only. In this case, the rest of the paper was scanned based on its structure, headings, figures.

## C.5 Analysis and synthesis

The papers remaining after the screening and evaluation of the search hits are fully read. During the reading of the sources, notes were kept on the floor systems mentioned and their characteristics. Notes were also taken of references to other papers and authors. The referenced sources were also screened and evaluated based on the same process as the initial search hits. If the source was deemed relevant, it was included in the literature study. The tables below give an overview of all sources included in the literature review.

Table C.3: Sources included in literature study research question 2 for flexible floor systems

| Search Engine | Authors                                    | Title                                                                                     | Year | Document type                    | DOI                    |
|---------------|--------------------------------------------|-------------------------------------------------------------------------------------------|------|----------------------------------|------------------------|
| Snow-balling  | Beton Son BV                               | Wing plaatvloer                                                                           | 2003 | <a href="#">Product sheet</a>    |                        |
| Snow-balling  | Bouwen met Staal                           | Duurzame stalen vloersystemen                                                             | 2013 | <a href="#">Report</a>           |                        |
| Snow-balling  | Consolis VBI                               | Productdatablad Leidingvloer 200                                                          |      | <a href="#">Product sheet</a>    |                        |
| Snow-balling  | Consolis VBI                               | Productdatablad Leidingvloer 260                                                          |      | <a href="#">Product sheet</a>    |                        |
| Snow-balling  | M. Cox, L. van Haren, E. Senden            | A flexible topfloor system with integrated heating and cooling for the Infra+ floorsystem | 2006 | <a href="#">Conference paper</a> |                        |
| Snow-balling  | M. den Boon, P. Fraanje                    | V(l)oer voor Vernieuwing: 19 moderne vloersystemen voor de bouw                           | 2007 | <a href="#">Report</a>           |                        |
| Snow-balling  | T. Dreßen                                  | Deckensysteme für flexible Nutzung als Beitrag zur Nachhaltigkeit von Gebäudestrukturen   | 2011 | <a href="#">Thesis</a>           |                        |
| Snow-balling  | Dycore                                     | De vloersystemen van Dycore: Een vloeroplossing voor elk project                          | 2016 | <a href="#">Product sheet</a>    |                        |
| Snow-balling  | Franz Oberndorfer GmbH                     | CLC Multifunktionsdecke                                                                   |      | <a href="#">Product sheet</a>    |                        |
| WoS           | J. Hegger, M. Claßen, J. Gallwoszus et al. | Multifunktionale Verbunddecke mit integrierter Gebäudetechnik                             | 2014 | <a href="#">Journal article</a>  | 10.1002/stab.201410170 |
| Snow-balling  | HOLCON B.V.                                | HOLCON vloer                                                                              |      | <a href="#">Product sheet</a>    |                        |
| Snow-balling  | U. Kuhlmann                                | 2010 Stahlbau Kalender                                                                    | 2010 | <a href="#">Report</a>           |                        |

|              |                                             |                                                                                                                    |      |                                 |                        |
|--------------|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------|---------------------------------|------------------------|
| Snow-balling | Lignatur                                    | Lignatur workbook                                                                                                  | 2014 | <a href="#">Product sheet</a>   |                        |
|              | Lignatur                                    | Dragende ideeën met hout                                                                                           | 2019 | <a href="#">Product sheet</a>   |                        |
| Known        | D. Meijer                                   | Infra+ Innovatief vloerconcept met integrale kostenbesparing                                                       | 1998 | <a href="#">Journal article</a> |                        |
| WoS          | M. Mensinger, M. Fontana, A. Frangi         | Entwicklung eines multifunktionalen Deckensystems mit erhöhter Ressourceneffizienz                                 | 2010 | <a href="#">Journal article</a> | 10.1002/stab.201001320 |
| WoS          | M. Olipitz                                  | Die CLC-Multifunktionsdecke: Ein hybrides Vollfertigteil mit erhöhter Nutzungsflexibilität und Ressourceneffizienz | 2017 | <a href="#">Journal article</a> | 10.1002/stab.201710483 |
| Snow-balling | P. Schaumann, P. Meyer, M. Mensinger et al. | Analyse des Tragverhaltens eines Deckensystems infolge eines Naturbrandszenarios für den Deckenhohlraum            | 2019 | <a href="#">Journal article</a> | 10.1002/bate.201800037 |
| Snow-balling | Slimline Buildings                          | Slimline constructie                                                                                               |      | <a href="#">Product sheet</a>   |                        |
| Snow-balling | Slimline Buildings                          | Slimline vloersysteem                                                                                              |      | <a href="#">Product sheet</a>   |                        |
| Snow-balling | TataSteel                                   | Handboek Star-Frame Solutions                                                                                      | 2011 | <a href="#">Product sheet</a>   |                        |
| Snow-balling | L. van Haren                                | HeCoFlex-topvloer: flexibele topvloer met geïntegreerde verwarming en koeling                                      | 2008 | <a href="#">Thesis</a>          |                        |
| Snow-balling | M. Wang                                     | Adaptable Raised Floor System For Open Building                                                                    | 2019 | <a href="#">Report</a>          |                        |

Table C.4: Sources included in literature study research question 2 for raised floors

| Search Engine | Authors                            | Title                                                                                                         | Year | Document type                    | DOI |
|---------------|------------------------------------|---------------------------------------------------------------------------------------------------------------|------|----------------------------------|-----|
| Snow-balling  | Nederlandse Normalisatie-instituut | NEN-EN 12825 Verhoogde vloere                                                                                 | 2001 | <a href="#">Norm</a>             |     |
| Known         | M. Wang                            | Adaptable Raised Floor System For Open Building                                                               | 2019 | <a href="#">Report</a>           |     |
| WoS           | Y. Wu, D. Su, W. Peng et al.       | Application of lifecycle assessment and finite element analysis in the design of raised access floor products | 2017 | <a href="#">Conference paper</a> |     |

Table C.5: Sources included in literature study research question 2 for suspended ceilings

| Search Engine | Authors                                      | Title                                                                  | Year | Document type                    | DOI                       |
|---------------|----------------------------------------------|------------------------------------------------------------------------|------|----------------------------------|---------------------------|
| Scopus        | A. Bannister                                 | Suspended ceilings – design and application                            | 1985 | <a href="#">Journal article</a>  | 10.1108/eb006218          |
| Snow-balling  | Nederlands Normalisatie-instituut            | NEN-EN 13964 Verlaagde plafonds - Eisen en beproevingsmethoden         | 2014 | <a href="#">Norm</a>             |                           |
| WoS           | S. Soroushian, M. Maragakis, A. Zaghi et al. | Numerical Simulation of Integrated Suspended Ceiling-Sprinkler Systems | 2015 | <a href="#">Conference paper</a> | 10.1061/9780784479117.162 |



# Appendix D Literature study circularity assessment methods

## D.1 Approach

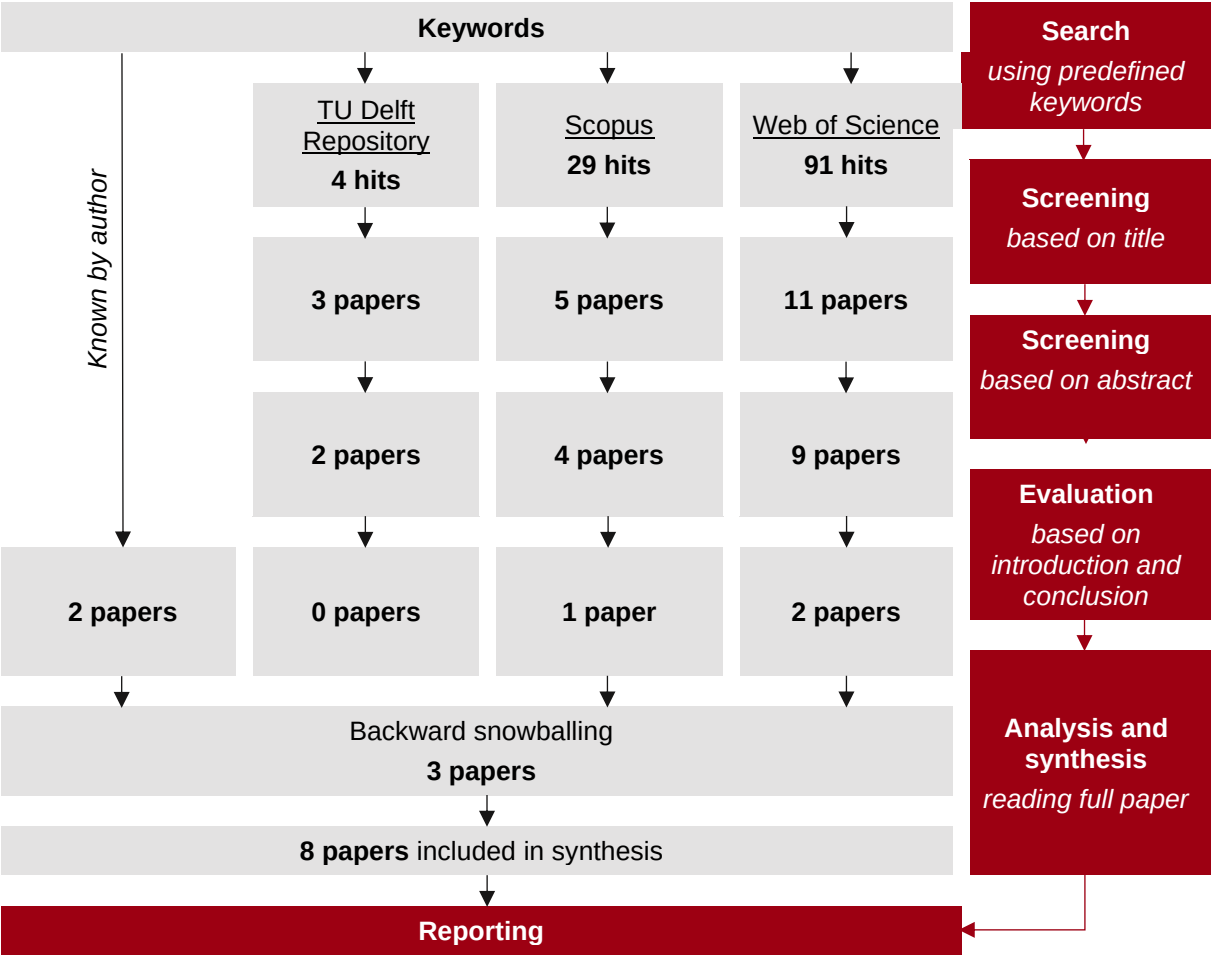


Figure D.1: Steps taken in literature review research question 3a

Figure D.1 provides an outline of the process of the literature study. Table D.1 gives the keywords used to formulate the search term.

Table D.1: Keywords for search term research question 3a

|                                                                                                                  |     |                                                                  |     |                                 |     |             |
|------------------------------------------------------------------------------------------------------------------|-----|------------------------------------------------------------------|-----|---------------------------------|-----|-------------|
| Assessment method*<br>Assessment method<br>Assessment methodology<br>Assessment tool<br>Rating<br>Index<br>Score | AND | Building<br>Structur*<br>Structure<br>Structural<br>Construction | AND | Components<br>Elements<br>Parts | AND | Circularity |
|------------------------------------------------------------------------------------------------------------------|-----|------------------------------------------------------------------|-----|---------------------------------|-----|-------------|

## D.2 Search

### D.2.1 Scopus

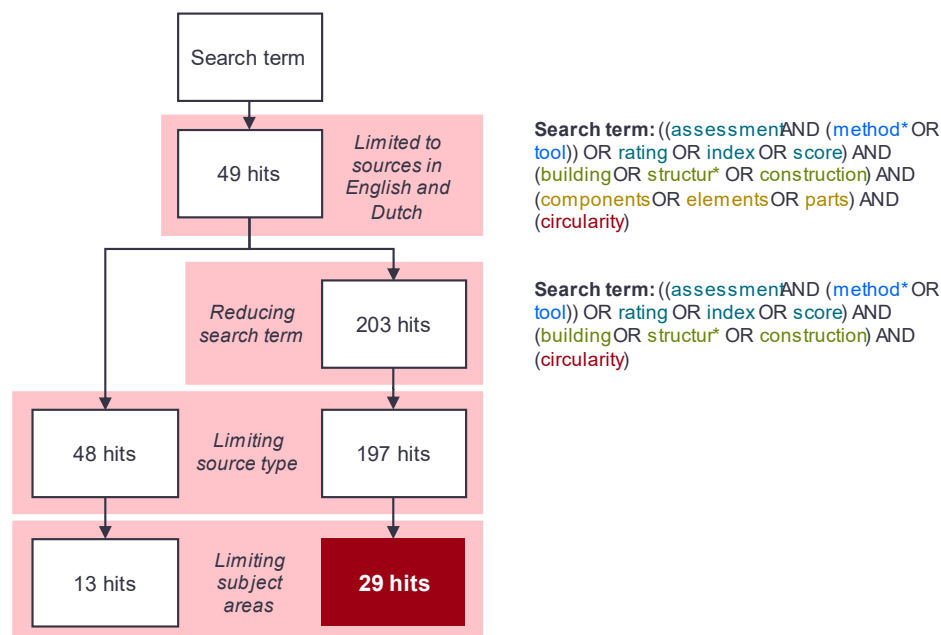


Figure D.2: Flow chart of filters applied to search term Scopus research question 3a

The search term was applied to the fields article title, abstract, and keywords, which is the standard setting of Scopus. Initially, four categories of keywords were included in the search term. To increase the number of hits, the keywords specifying elements of the structure rather than the structure as a whole were dropped. Right away, an initial filter was applied to limit the search to sources in Dutch and English. This results in the first amount of hits, shown at the top of Figure D.2.

#### Limiting source type

The following source types are included in the search:

- Journals

#### Limiting subject areas

Certain subject areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain subject areas is outlined below.

- Subject areas unrelated to structures or buildings  
*Excluded subject areas: Agricultural and biological sciences, Earth and planetary sciences, Medicine, Social sciences, Biochemistry, genetics and molecular biology, Physics and astronomy, Business, management and accounting, Veterinary, Economics, econometrics and finance, Immunology and microbiology, Neuroscience, Psychology, Chemical engineering, Chemistry, Pharmacology, toxicology and pharmaceuticals, Decision sciences, Arts and humanities, Health professions, Dentistry, and Nursing.*

## D.2.2 TU Delft Repository

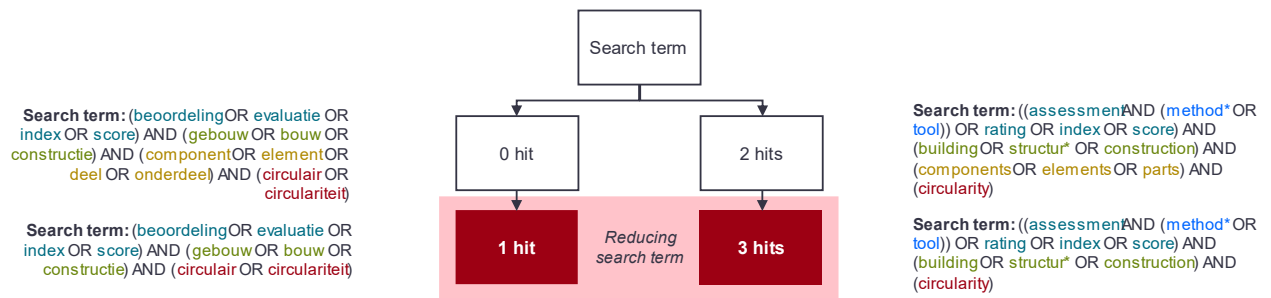


Figure D.3: Flow chart of filters applied to search term TU Delft Repository research question 3a

As shown in Figure D.3, the search terms were put into the TU Delft Repository both in Dutch and in English. Initially, four categories of keywords were included in the search term. To increase the number of hits, the keywords specifying elements of the structure rather than the structure as a whole were dropped.

## D.2.3 Web of Science

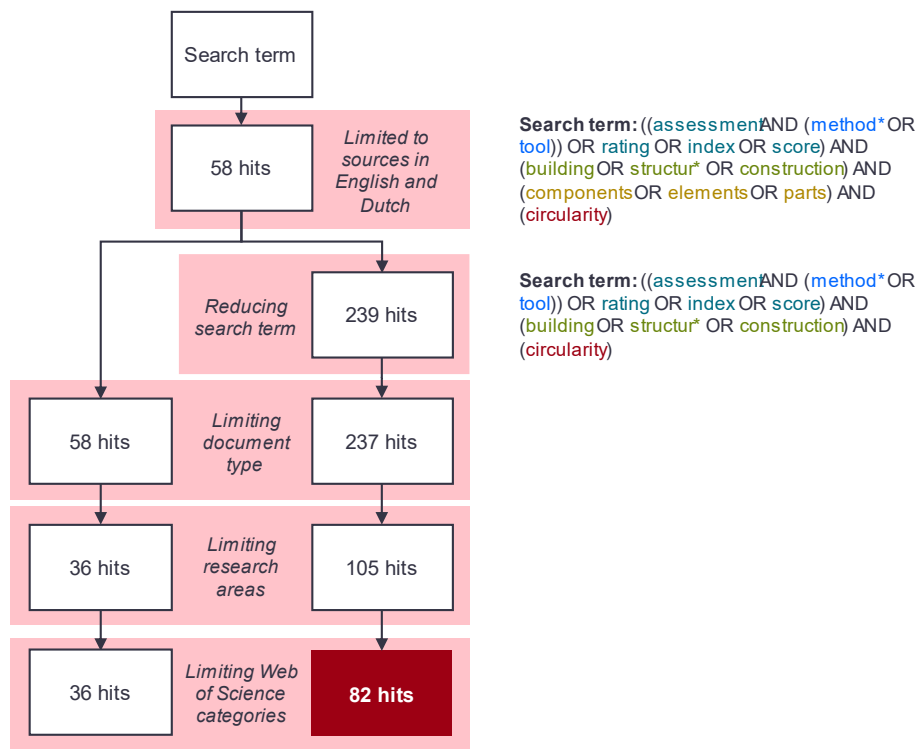


Figure D.4: Flow chart of filters applied to search term Web of Science research question 3a

The search term for Web of Science was set to search in Topic, which includes the title, abstract, author keywords, and Keywords Plus. The initial results were directly filtered to only include sources in Dutch and English. Initially, all four categories of keywords were included in the search term. To increase the number of hits, the keywords specifying elements of the structure rather than the structure as a whole were dropped.

### Limiting document type

The following document types are included in and excluded from the search results.

#### Included

- Article
- Proceedings paper
- Review
- Early access article
- Reprinted article

#### Excluded

- Editorial material
- Note
- Letter
- Book chapter
- Retracted publication
- Data paper
- Correction
- Book review
- Meeting abstract
- Software review
- Book

### Limiting research areas

Certain research areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain research areas is outlined below.

- Unrelated to structures or buildings

*Excluded research areas: Agriculture, Mathematical computational biology, Anthropology, Biomedical social sciences, Business economic, Cardiovascular system cardiology, Cell biology, Chemistry, Electrochemistry, Energy fuels, Evolutionary biology, Fisheries, Geochemistry, Geriatrics gerontology, Life sciences biomedicine other topics, Marine freshwater biology, Medical ethics, Metallurgy metallurgical engineering, Mineralogy, Operations research management science, Ophthalmology, Optics, Physics, Reproductive biology, Social issues, Social sciences other topics, Zoology, Radiology nuclear medicine medical imaging, Neurosciences neurology, Remote sensing, Psychology Surgery, Food science technology, imaging science photography technology, Orthopaedics, Astronomy astrophysics, Biochemistry molecular biology, General internal medicine, Pharmacology pharmacy, Physical geography, Plant science, Respiratory system, Biotechnology applied microbiology, Immunology, Sport sciences, Telecommunication, Allergy, Anatomy morphology, Art, Audiology speech language pathology, Dermatology, Endocrinology metabolism, Gastroenterology hepatology, Genetics heredity, Geochemistry geophysics, Linguistics, Hematology, Medical informatics, Meteorology atmospheric sciences, Obstetrics gynaecology, Physiology, Rehabilitation, Toxicology, Veterinary sciences, and Zoology.*

### Limiting Web of Science categories

All sources covered by the Web of Science core collection are also assigned a subject category. These categories are similar to the research areas but can still provide the next level of filtering.

- Unrelated to structures or buildings

*Excluded Web of Science categories: Engineering biomedical, Engineering chemical, Nanoscience nanotechnology, and Engineering electrical electronic.*

## D.3 Screening

The screening of all the sources was done in two phases. First, all of the hits were screened based on their title. Then, a second screening took place based on the abstracts of the remaining sources. In some cases, sources were also excluded because the full article was not available through either open access or TU Delft resources. Duplicate hits were also filtered. In Figure D.1, duplicate hits are counted under the search engine they were first found with, with the search order being left to right.

### Screening based on titles

Based on the title, certain hits were excluded according to the following criteria:

- Subject area unrelated to circularity  
The aim was to identify assessment methods for circularity. Hits that were clearly unrelated to circularity were excluded.
- Subject area unrelated to the building industry  
The circularity methods should be applicable to building components. Hits from subject areas that operate at a different scale were excluded.

### Screening based on abstracts

Hits were included if the abstract contains mention of or reference to an assessment method or tool that could be relevant in the context of building components.

## D.4 Evaluation

Further evaluation of the search hits for the inclusion in the literature study was done based on the introduction and conclusion. The criteria for inclusion is similar to that of the screening based on the abstract, the introduction or the conclusion should contain mention of or reference to an assessment method or tool that could be relevant in the context of building components. In some cases, no conclusive judgement could be made based on the introduction and conclusion of the paper only. In this case, the rest of the paper was scanned based on structure, headings, and figures.

## D.5 Analysis and synthesis

The papers remaining after the screening and evaluation of the search hits were fully read. During the reading of the sources, notes were kept on the assessment method mentioned or applied throughout the texts. Notes were also taken of references to other papers and authors. The referenced sources were also screened and evaluated based on the same process as the initial search hits. If the source was deemed relevant, it was included in the literature study. The table below gives an overview of all the sources included in the literature review.

Table D.2: Sources included in literature study research question 3a

| Search Engine | Authors                                                         | Title                                                                                                                                | Year | Document type                    | DOI                             |
|---------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------|---------------------------------|
| Known         | D. Cottafava, M. Ritzen                                         | Circularity indicator for residential buildings: Addressing the gap between embodied impacts and design aspects                      | 2020 | <a href="#">Journal article</a>  | 10.1016/j.resconrec.2020.105120 |
| WoS           | E. Dieckmann, L. Scheldrick, M. Tennant, R. Myers, C. Cheeseman | Analysis of Barriers to Transitioning from a Linear to a Circular Economy for End of Life Materials: A Case Study for Waste Feathers | 2020 | <a href="#">Journal article</a>  | 10.3390/su12051725              |
| Scopus/WoS    | A. Godelet, H. Schuster                                         | A material world: Study of a circular economy approach in architecture - Development of an index for the construction industry       | 2018 | <a href="#">Conference Paper</a> |                                 |
| Snow-balling  | P. Griffiths, S. Cayzer                                         | Design of Indicators for Measuring Product Performance in the Circular Economy                                                       | 2016 | <a href="#">Conference Paper</a> | 10.1007/978-3-319-32098-4_8     |
| Known         | Platform CB'23                                                  | Meten van circulariteit: Werkafspraken voor een circulaire bouw                                                                      | 2020 | <a href="#">Report</a>           |                                 |
| Snow-balling  | C. Van Schaik                                                   | Circular building foundations                                                                                                        | 2019 | <a href="#">Thesis</a>           |                                 |
| Snow-balling  | J. Verberne                                                     | Building circularity indicators - an approach for measuring circularity of a building                                                | 2016 | <a href="#">Thesis</a>           |                                 |
| WoS           | M. Wiprächtiger, M. Haupt, N. Heeren, E. Waser, S. Hellweg      | A framework for sustainable and circular system design: Development and application on thermal insulation materials                  | 2020 | <a href="#">Journal article</a>  | 10.1016/j.resconrec.2019.104631 |

# Appendix E Literature study flexibility assessment methods

## E.1 Approach

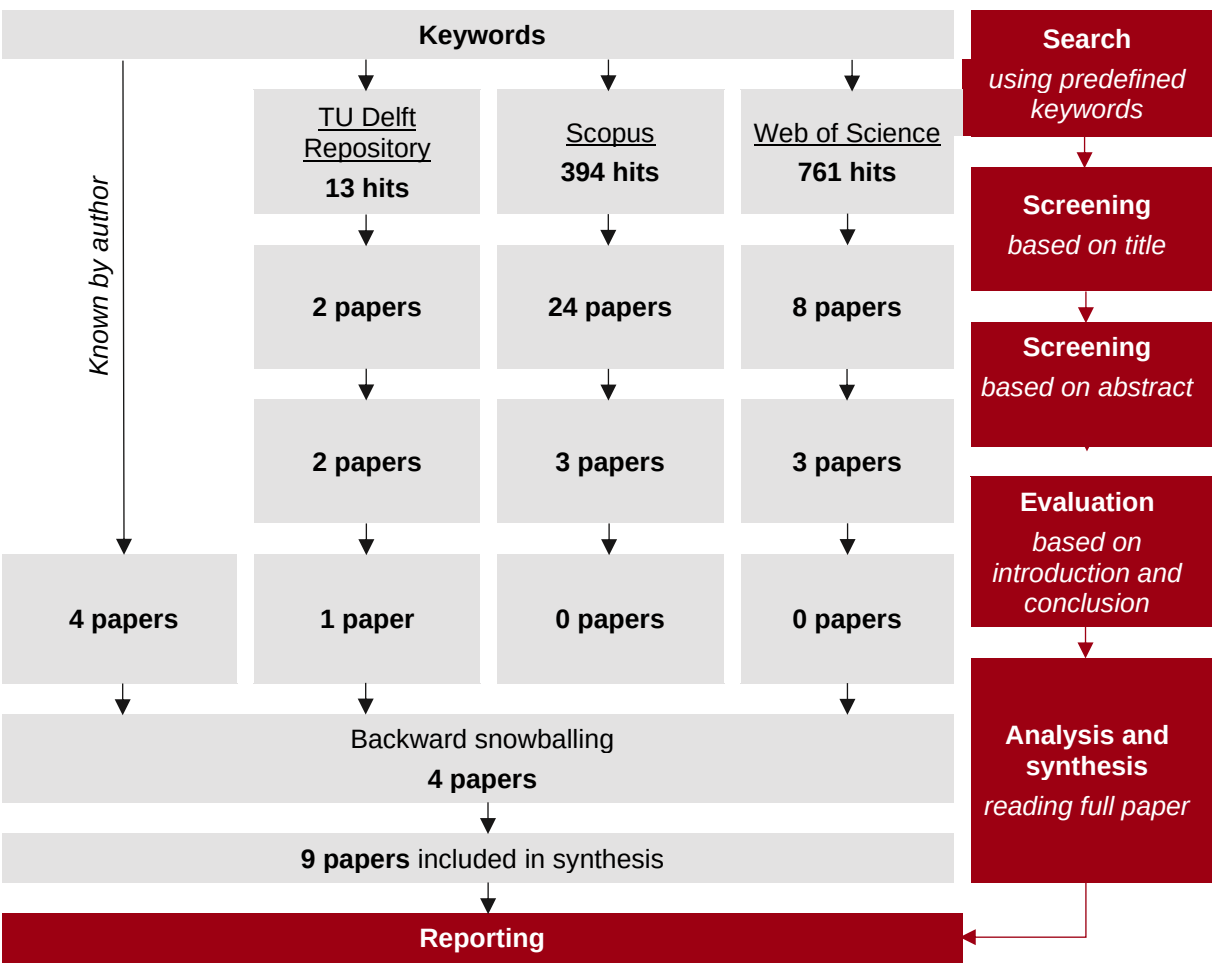


Figure E.1: Steps taken in literature review research question 3b

Figure E.1 outlines the process of the literature study done to identify the existing methods to assess the flexibility of building components. Table E.1 gives the keywords used to formulate the search term.

Table E.1: Keywords for search term research question 3b

|                                                                                                                  |     |                                                                  |     |                                 |     |                                                                             |
|------------------------------------------------------------------------------------------------------------------|-----|------------------------------------------------------------------|-----|---------------------------------|-----|-----------------------------------------------------------------------------|
| Assessment method*<br>Assessment method<br>Assessment methodology<br>Assessment tool<br>Rating<br>Index<br>Score | AND | Building<br>Structur*<br>Structure<br>Structural<br>Construction | AND | Components<br>Elements<br>Parts | AND | Flexib*<br>Flexibility<br>Flexible<br>Adaptab*<br>Adaptability<br>Adaptable |
|------------------------------------------------------------------------------------------------------------------|-----|------------------------------------------------------------------|-----|---------------------------------|-----|-----------------------------------------------------------------------------|



## E.2 Search

### E.2.1 Scopus

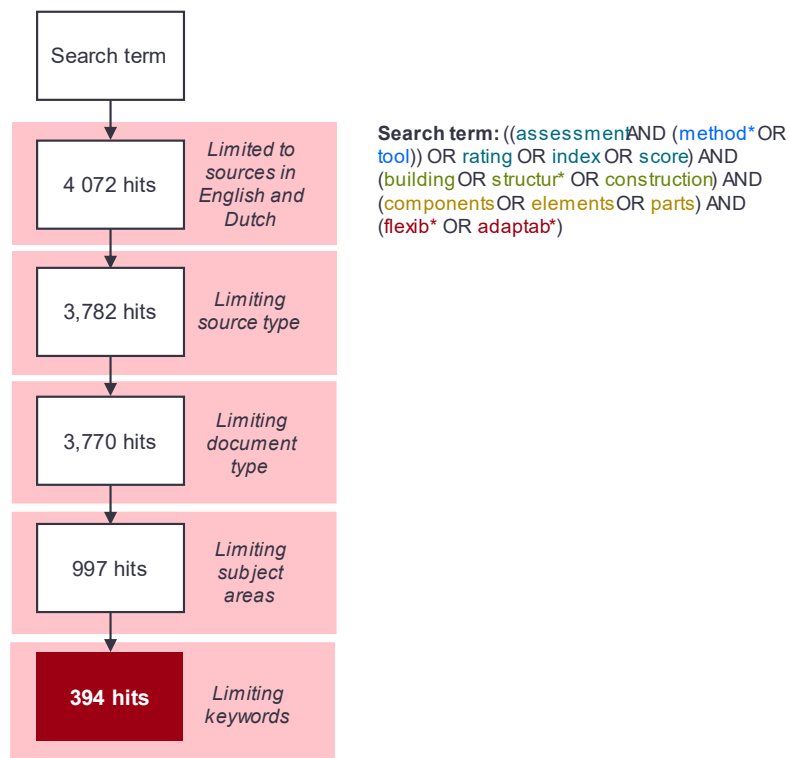


Figure E.2: Flow chart of filters applied to search term Scopus research question 3b

The search term was applied to the fields article title, abstract, and keywords, which is the standard setting of Scopus. Right away, an initial filter was applied to limit the search to sources in Dutch and English. This results in the first amount of hits, shown at the top of Figure E.2.

#### Limiting source type

The following source types are included in the search:

- Journals
- Conference materials
- Trade journals

#### Limiting document type

The inclusion of document types is based on their perceived relevance to the research at hand and the expected amount of primary information to be found in the document. An overview of both the included and excluded document types is given below.

##### Included

- Article
- Conference paper
- Review

##### Excluded

- Erratum
- Note
- Short survey

#### Limiting subject areas

Certain subject areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain subject areas is outlined below.

- Subject areas unrelated to structures or buildings

*Excluded subject areas: Material science, Medicine, Physics and Astronomy, Mathematics, Social Sciences, Earth and planetary sciences, Energy, Biochemistry, Genetics and molecular biology, Agricultural and biological sciences, Chemistry, Chemical Engineering, Business, management and accounting, Decision sciences, Psychology, Neuroscience, Arts and Humanities, Nursing, Pharmacology, toxicology and pharmaceuticals, Health professions, Economics, econometrics and finance, Immunology and microbiology, Dentistry, and Veterinary.*

### Limiting keywords

A number of keywords were excluded from the remaining search results. The reasoning for excluding certain keywords is outlined below.

- **Keywords that indicate a different interpretation of the search term than intended**  
*Excluded keywords: Stiffness, Elasticity, Flexible pavements, Ductility, Flexibility matrices, and Rigid structures.*
- **Keywords that indicate modelling or structural analysis**  
*Excluded keywords: Finite element method, Risk assessment, Structural analysis, Damage detection, Computer simulation, Modal analysis, Structural dynamics, Numerical model, Numerical methods, Seismic design, Structural health monitoring, Dynamic response, Dynamics, Earthquakes, Vibration, Fatigue of materials, Nondestructive examination, Structural response, Finite element analysis, Seismic response, Damping, Computational methods, Damage index, Monte Carlo Methods, Nonlinear analysis, Regression analysis, Simulation, Stiffness matrix, Strain energy, Equations of motion, Fatigue, Fluid Structure Interaction, Strain, Vibration analysis, Buckling, Computation theory, Deflection, Natural frequencies, and Structural loads.*
- **Keywords that are not related to structures or buildings**  
*Excluded keywords: Neural networks, Data structures, Automation, Artificial intelligence, Genetic algorithms, Learning systems, Query languages, Actuators, Human, Fuzzy sets, Stochastic systems, Fluid Structure Interaction, Pressure Vessels, Students, Aerodynamics, Antennas, Complex networks, Computer architecture, Control systems, Data mining, Distributed computer systems, Hydrodynamics, Information retrieval, Location, Refractive index, Roads and streets, Robotics, Soils, United states, and Damage.*

### E.2.2 TU Delft Repository

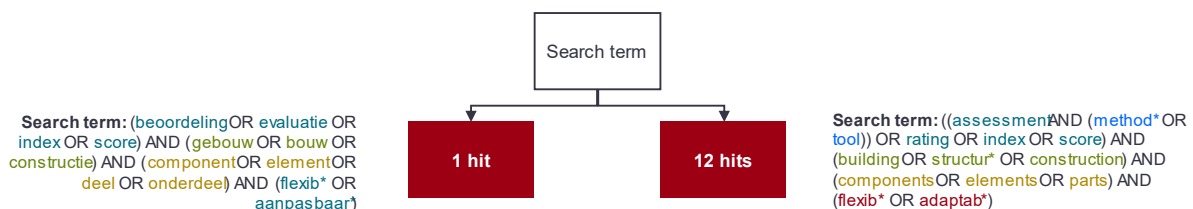


Figure E.3: Flow chart of filters applied to search term TU Delft Repository research question 3b

As shown in Figure E.3, the search terms were put into the TU Delft Repository both in Dutch and in English.

### E.2.3 Web of Science

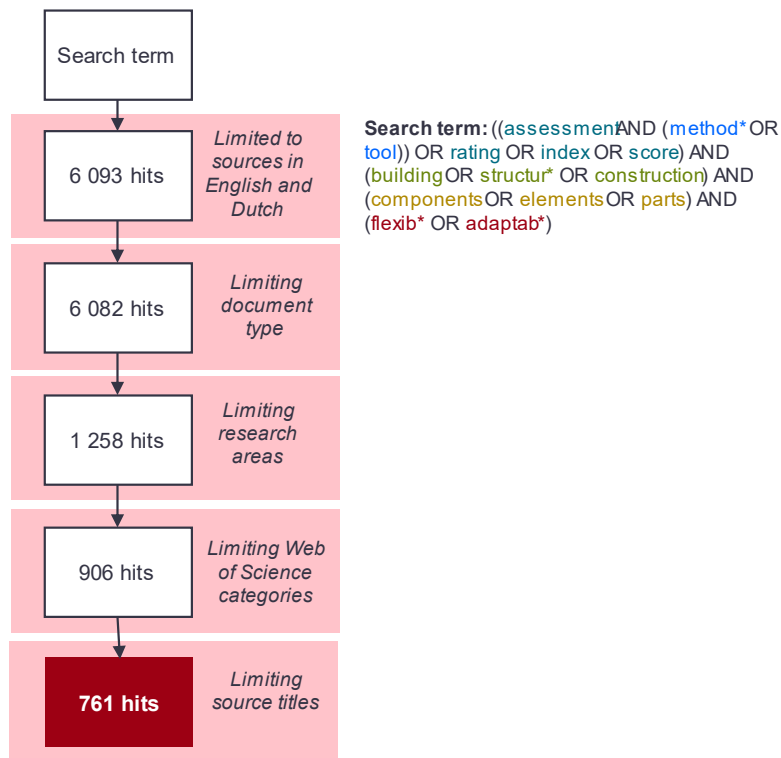


Figure E.4: Flow chart of filters applied to search term Web of Science research question 3b

The search term for Web of Science was set to search in Topic, which includes the title, abstract, author keywords, and Keywords Plus. The initial results were directly filtered to only include sources in Dutch and English.

#### Limiting document type

The document types selected are comparable to those selected for Scopus.

##### Included

- Article
- Proceedings paper
- Review
- Early access article

##### Excluded

- Editorial material
- Note
- Book chapter
- Retracted publication
- Correction
- Book review
- Software review

#### Limiting research areas

Certain research areas were excluded from the search as they do not fit the type of information relevant to this research and its scope. The reasoning for excluding certain research areas is outlined below.

- Unrelated to structures or buildings  
*Excluded research areas: Computer science, materials science, Chemistry, Biochemistry molecular biology, Physics, Science technology other topics, Optics, Energy fuels, Business economic, Instruments instrumentation, Telecommunications, Biophysics, Automation control systems, Psychology, Pharmacology pharmacy, Geology, Polymer science, Public environmental occupational health, Mathematical computational biology, Neurosciences neurology, Health care sciences services, Biotechnology applied microbiology, Transportation, Thermodynamics, Water resources, Nuclear science technology, Acoustics, Agriculture,*

*Imaging science photographic technology, Robotics, Radiology nuclear medicine medical imaging, Metallurgy metallurgical engineering, Remote sensing, Psychiatry, Life sciences biomedicine other topics, Cell biology, electrochemistry, Astronomy astrophysics, Medical informatics, Meteorology atmospheric sciences, Social sciences other topics, General internal medicine, Zoology, Rehabilitation, Information science library science, Mathematical methods in social sciences, Marine freshwater biology, Genetics heredity, Physical geography, Crystallography, Oceanography, Food science technology, Forestry, Spectroscopy, Sport sciences, Nursing, Public administration, Plant sciences, Research experimental medicine, Biodiversity conservation, Evolutionary biology, Physiology, Linguistics, Orthopaedics, Surgery, Toxicology, Urban studies, Geochemistry geophysics, Microbiology, Geriatrics gerontology, oncology, Endocrinology metabolism, Behavioural sciences, Cardiovascular system cardiology, Immunology, Paediatrics, Fisheries, Mining mineral processing, Anaesthesiology, Audiology speech language pathology, Nutrition dietetics, Geography, Infectious diseases, Respiratory system, Sociology, Virology, Demography, Microscopy, Mineralogy, Ophthalmology, and Anatomy morphology.*

### **Limiting Web of Science categories**

All sources covered by the Web of Science core collection are also assigned a subject category. These categories are similar to the research areas but can still provide the next level of filtering.

- Unrelated to structures or buildings

*Excluded Web of Science categories: Engineering electrical electronic, Engineering aerospace, Engineering geological, Engineering biomedical, Engineering marine, Engineering chemical, Engineering ocean, Engineering petroleum, Transplantation, Urology nephrology, Ergonomics, Veterinary sciences, Dentistry oral surgery medicine, Humanities multidisciplinary, Obstetrics gynaecology, Anthropology, Development studies, Emergency medicine, Entomology, Gastroenterology hepatology, International relations, Medicine legal, Pathology, Political science, Substance abuse, Archaeology, Dance, History philosophy of science, Integrative complementary medicine, Law, Medical laboratory technology, Reproductive biology, Rheumatology, Social issues, and Social sciences biomedical.*

### **E.3 Screening**

The screening of all the sources found was done in two phases. First, all of the hits were screened based on their title. Then, a second screening took place based on the abstracts of the remaining sources. In some cases, sources were also excluded because the full article was not available through either open access or TU Delft resources. Duplicate hits were also filtered. In Figure E.1, the duplicate hits are counted under the search engine they were first found with, with the search order being left to right.

#### **Screening based on titles**

Based on the title, certain hits were excluded according to the following criteria

- Subject area unrelated to flexibility or adaptability  
The aim was to identify assessment methods for flexibility. Hits that were clearly unrelated to flexibility were excluded.
- Subject area unrelated to the building industry  
The flexibility methods should be applicable to building components. Hits from subject areas that operate at a different scale were excluded.

#### **Screening based on abstracts**

Hits were included if the abstract contains mention of or reference to an assessment method or tool that could be relevant in the context of building components

### **E.4 Evaluation**

Further evaluation of the search hits for the inclusion in the literature study was done based on the introduction and conclusion. The criteria for inclusion is similar to that of the screening based on the abstract, the introduction or the conclusion should contain mention of or reference to an assessment method or tool that could be relevant in the context of building components. In some cases, no conclusive

judgement could be made based on the introduction and conclusion of the paper only. In this case, the rest of the paper was scanned based on structure, headings, and figures.

## E.5 Analysis and synthesis

The papers remaining after the screening and evaluation of the search hits were fully read. During the reading of the sources, notes were kept on the assessment method mentioned or applied throughout the texts. Notes were also taken of references to other papers and authors. The referenced sources were also screened and evaluated based on the same process as the initial search hits. If the source was deemed relevant, it was included in the literature study. The table below gives an overview of all the sources included in the literature review.

Table E.2: Sources included in literature study research question 3b

| Search Engine | Authors                                 | Title                                                                                                                                                                       | Year | Document type                    | DOI                           |
|---------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------|-------------------------------|
| Snow-balling  | J. Andrade, L. Bragança                 | Assessing building's adaptability at early design stages                                                                                                                    | 2019 | <a href="#">Conference paper</a> |                               |
| Snow-balling  | E. Durmisevic                           | Transformable building structures: Design for disassembly as a way to introduce sustainable engineering to building design & construction                                   | 2006 | <a href="#">Thesis</a>           |                               |
| TU Delft/WoS  | B. Geldermans, M. Tenpierik, P. Luscure | Circular and Flexible Indoor Partitioning: A Design Conceptualization of Innovative Materials and Value Chains                                                              | 2019 | <a href="#">Thesis</a>           | 10.3390/buildings 9090194     |
| Known         | R. Geraedts                             | FLEXIS Communicatie over en beoordeling van flexibiliteit tussen gebouwen en installaties                                                                                   | 1996 | <a href="#">Book</a>             |                               |
| Known         | R. Geraedts                             | FLEX 4.0: A Practical Instrument to Assess the Adaptive Capacity of Buildings                                                                                               | 2016 | <a href="#">Journal article</a>  | 10.1016/j.egypro. 2016.09.102 |
| Known         | R. Gijsber, J. Lichtenberg              | Comparison of adaptability measures in building design - CSA Method: Functionally effective and technically efficient design founded on (future) user demands               | 2012 | <a href="#">Conference paper</a> |                               |
| Known         | M. Hermans, R. Geraedts, E. Rijn et al. | Gebouwen met toekomstwaarde! Het bepalen van de toekomstwaarde van gebouwen vanuit het perspectief van adaptief vermogen, financieel rendement en duurzaamheid: Eindrapport | 2014 | <a href="#">Report</a>           |                               |
| Snow-balling  | E. Koopman                              | Inventarisatie en kwalificatie van constructieve flexibiliteit                                                                                                              | 2010 | <a href="#">Thesis</a>           |                               |
| Snow-balling  | D. Krijntjes                            | Service Life estimation through Structural Flexibility assessment                                                                                                           | 2016 | <a href="#">Thesis</a>           |                               |

## Appendix F Flexibility assessment method weights

The weights for the flexibility assessment method are determined based on the method proposed by Song and Kang (2016). The method consists of two parts. First, the priorities between the different characteristics of flexibility are determined and then the weights are assigned

### F.1 Determination of priorities

#### Step 1: Hierarchical structuring

The first step is to create a hierarchy using attributes and entities, similar to in the AHP. At the top of the hierarchy should be the goal, which branches out into attributes and entities required to reach this goal. This hierarchy is similar to the one made in Chapter 5.1. Figure 7 shows the relationships between the different attributes and entities, but for the determination of priorities, the characteristics need to be arranged into groups with a maximum of 3 entities. This grouping is given in Figure F.1. Group I contains entities that are important to the robustness of the structure, group II consists of entities important to demountability, and group III contains entities important to modularity. Based on Figure 7, multiple different groupings were possible, but as it is only the start for the comparative prioritizing process, the initial grouping should not affect the final prioritizing too much.

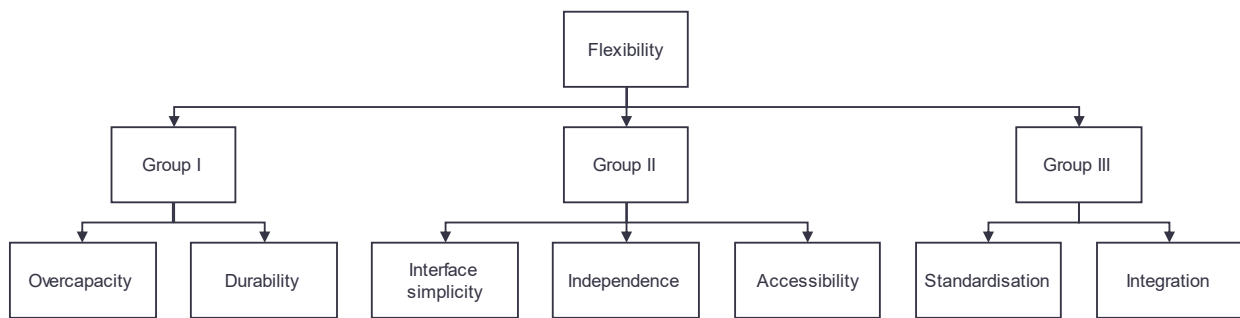


Figure F.1: Hierarchy structure (step 1)

### Step 2: Setting priorities of entities within each group

After creating a hierarchy, the entities included in each group are given priorities. These priorities are shown in Figure F.2.

In group I overcapacity is given priority over durability because it is directly important for the ability of a building component to be used in different situations. As shown in Figure 7, overcapacity is also required for many different aspects of flexibility. Durability is of a more general importance as components that are to be used in new or different situations need to still be functional by the time this change is desired.

For group II, priority has been given to accessibility because components and systems need to be accessible in order to be flexible. If a system cannot be reached, adaptation of the system would become very complicated. Interface simplicity is placed above independence because the adaptation of independent elements requires that elements can be disconnected or separated. If the separation of individual elements takes too much effort, adaptations are not likely to be realised.

Standardisation is prioritized in group III. When sizes or connections are standardized, it becomes much easier to adapt an element or reuse it in a new situation. In that case, no specialised tools or elements are required to add different elements or place the original element in a new situation. With regard to flexibility, integration is a characteristic that is beneficial but not essential. Adaptation of systems is simplified if all elements of the system are technically coupled, but it is not required to achieve flexibility.

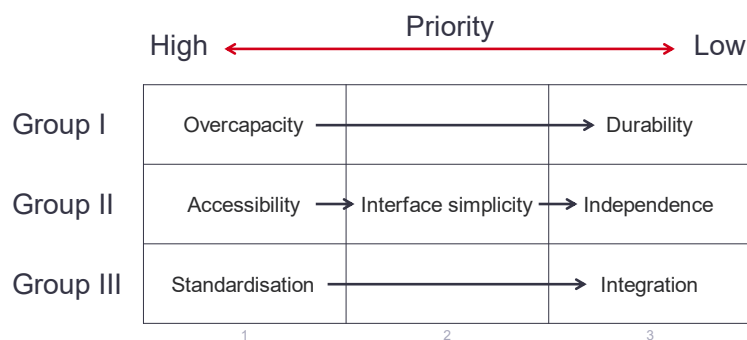


Figure F.2: Priority in the entities of each group (step 2)

### Step 3: Setting a priority between the entities with the same priority from the different groups

After giving priorities to entities of the same group, the priority between the entities with the same priority from the different groups is determined. Thus, the entities with a high priority from each group are compared and priorities are assigned. The same is done for the entities with a low priority. Due to the number of technical characteristics of flexibility, there is only one entity with an intermediate priority. For now, this entity will not be compared to other entities.

Out of the high priority entities, accessibility is prioritized because a system cannot be adapted if it cannot be accessed. Overcapacity is prioritized after accessibility to allow for changes in use and requirements. Different forms of use have different technical specifications, as future use-cases are unknown during the design phase these can only be accounted for through overcapacity.



For the lower priority entities, independence of systems with different functions and service lives is prioritized over the other two entities because this separation allows for adaptation or replacement of one system without affecting other systems. Adaptation of systems is greatly complicated when systems of different services lives or functions are intertwined. Durability is prioritized over integration as it is more important that flexible elements can withstand time and the wear and tear of multiple adaptations than it is that all elements of the same system are combined into one element. As mentioned before, integration is beneficial but not essential to flexibility.

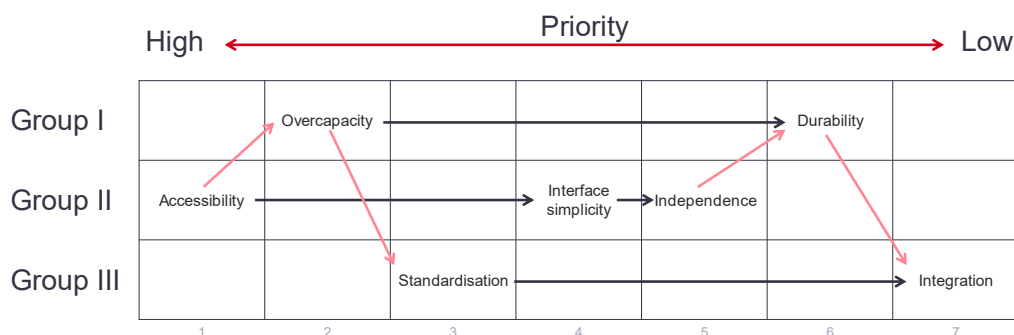


Figure F.3: Priority in equally ranked entities of each group (step 3)

#### Step 4: Setting priorities between the entities with adjoined priorities

In the final step of prioritization, the priorities of entities with adjoined priorities are checked and confirmed. This means that all the entities in Figure F.3 should be connected through an arrow to the entities directly to their left and to their right. The arrow between entities confirms a direct comparison. Where adjoined entities are not yet connected by an arrow, additional comparisons need to be made. The comparison process and the resulting changes to the prioritization are illustrated in Figure F.4. In Figure F.4, the names of the flexibility characteristics are abbreviated for legibility.

First, the entities of interface simplicity and standardisation are compared. Here, interface simplicity is prioritized over standardisation because in order to adapt systems or parts of systems they need to be separable. As mentioned, if this takes too much effort, adaptations are less likely to be realised. Standardised connections are important, but if these standardised connections are complicated or hard to separate, adaptation of these standardised elements is less likely.

Second, a direct comparison between overcapacity and interface simplicity is done. Here, the different functions of a floor system are considered. For the structural function overcapacity has priority, as without overcapacity for the load-bearing properties, the element can only be applied in the same function or a 'lighter' function. Especially considering residential buildings as a starting point, this greatly reduces the flexibility for use in a different function. When it comes to building services, it is not likely that adaptations are easily implemented without interface simplicity. However, without overcapacity for building services, the floor can only accommodate desired changes if they require the same or lower spatial or technical specifications. If the floor element cannot facilitate the desired changes, the actions required to achieve the changes are indeed not relevant. Therefore, overcapacity is prioritized over interface simplicity, but the difference is slight.

Third, is the comparison between standardisation and independence. Here, independence is prioritized above standardisation because the entanglement of systems with different functions and service lives greatly complicates all aspects of flexible design, as can be seen by the connections in Figure 7. Standardisation is of importance because it simplifies the exchange, addition, or upgrades of elements. However, if the functions and service lives within an element are entwined, the benefits of standardisation are hampered.

Finally, standardisation and durability are compared. Without a certain degree of standardisation, it might be difficult to alter durable elements by the time adaptation is desired. For non-standardised elements, specialised tools or components would be required to benefit from the durability of the element. Therefore standardisation is prioritized above durability.

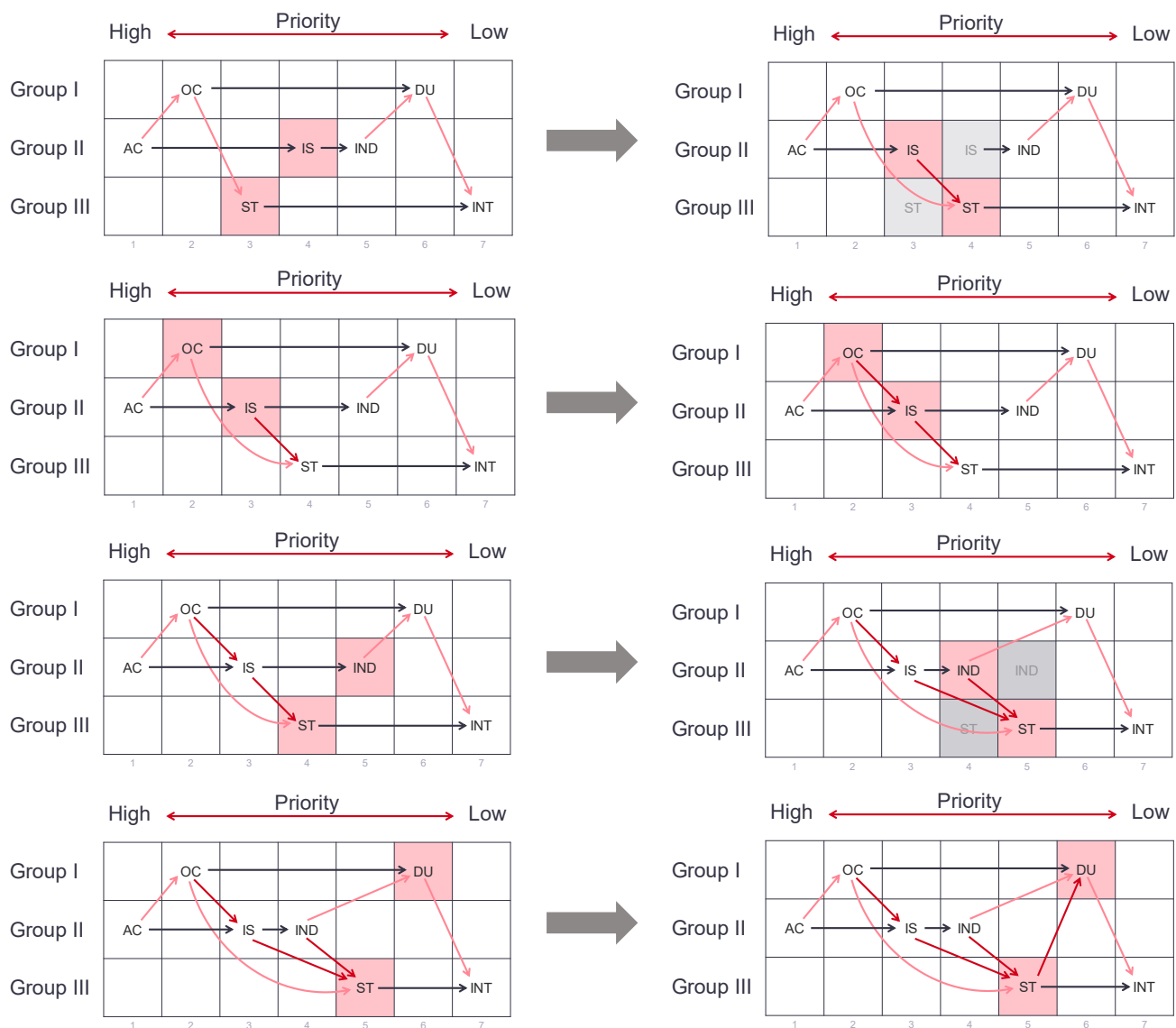


Figure F.4: The comparison process between adjoined entities (step 4)

## F.2 Assigning weights

Once the priority order of all the entities is determined, the weights are assigned. Pairwise comparisons are made between entities of adjoined properties. In these pairwise comparisons, the entity with a higher priority is given a score of 10 points and that with a lower priority is given a lower relative score. After determining the relative importance values of the entities from the highest to the lowest priority, a score range is set for the entire set of entities. This is done by considering the relative importance difference between the highest priority entity and the lowest priority entity. Table F.1 shows the weighting of the different entities. The lightly coloured cells show where the relative scores have been filled out and the brightly coloured cells in the bottom row give the final weights for each entity.

Table F.1: Results of the comparison between adjoined entities

| Rank     | 1             | 2            | 3                    | 4            | 5               | 6          | 7           |
|----------|---------------|--------------|----------------------|--------------|-----------------|------------|-------------|
| Entities | Accessibility | Overcapacity | Interface simplicity | Independence | Standardisation | Durability | Integration |
| AC:OC    | 10            | 8            |                      |              |                 |            |             |
| OC:IS    |               | 10           | 9                    |              |                 |            |             |

|             |       |       |       |       |       |       |       |
|-------------|-------|-------|-------|-------|-------|-------|-------|
| IS:IND      |       |       | 10    | 8     |       |       |       |
| IND:ST      |       |       |       | 10    | 7     |       |       |
| ST:DU       |       |       |       |       | 10    | 7     |       |
| DU:INT      |       |       |       |       |       | 10    | 4     |
| Score ratio | 10,00 | 8,00  | 7,20  | 5,76  | 4,03  | 2,82  | 1,13  |
| Score bound | 10    |       |       |       |       |       | 5     |
| Conversion  | 10,00 | 9,00  | 8,60  | 7,88  | 7,02  | 6,41  | 5,00  |
| Weights     | 0,186 | 0,167 | 0,160 | 0,146 | 0,130 | 0,119 | 0,093 |

## Appendix G Airborne sound insulation

The airborne sound insulation is calculated using the plateau method (van der Linden et al., 2013). This method takes into account the effect of coincidence into the prediction of the sound insulation. The sound insulation is determined in three parts, as illustrated in Figure G.1. Part I ( $R_I$ ) regards the range before the area of influence around the coincidence frequency, part II ( $R_{II}$ ) is the range around the coincidence frequency, and part III ( $R_{III}$ ) regards the range after the area of influence around the coincidence frequency.

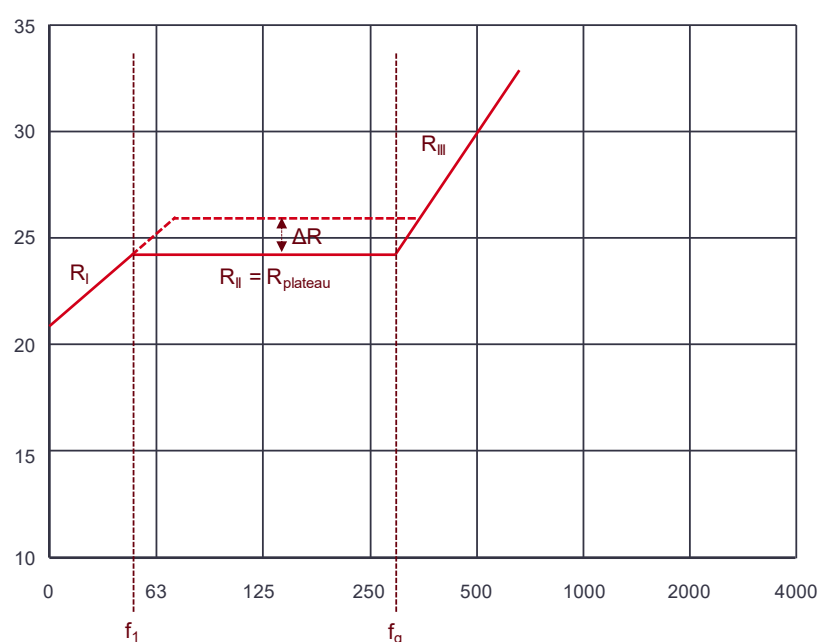


Figure G.1: Adapted from 'Plateau method' (van der Linden et al., 2013)

The ranges are marked by the frequencies  $f_1$  and  $f_g$ :

$$f_g = \frac{f_g * d}{d}$$

Where:

- $f_g$  is the upper threshold frequency of the plateau [Hz]
- $f_g * d$  is the material-dependent constant [Hz \* mm]
- $d$  is the thickness of the structure [mm]

$$f_1 = 1.57 * f_g * \eta^{\frac{1}{2}}$$

Where:

$f_1$  is the lower threshold frequency of the plateau [Hz]  
 $\eta$  is the loss factor

The sound insulation for  $f < f_1$ :

$$R_{alz} = 20 * \log(m) + 20 * \log\left(\frac{f}{250}\right)$$

Where:

$m$  is the mass [kg/m<sup>2</sup>]  
 $f$  is the frequency [Hz]

The sound insulation for  $f_1 < f < f_g$ :

$$R_{plateau} = 20 * \log(m * f_g) + 10 * \log(\eta) - 44$$

The sound insulation for  $f > f_g$ :

$$R = R_{plateau} + 25 * \log\left(\frac{f}{f_g}\right)$$

For structures with a mass greater than 70 kg/m<sup>2</sup>, the plateau has to be increased by:

$$\Delta R = 20 * \log\left(\frac{m}{70}\right)$$

Where:

$\Delta R$  is the increase in sound insulation [dB]

## G.1 Current design

Table G.1: Airborne sound insulation current design

| Properties                           |               |   |                        |
|--------------------------------------|---------------|---|------------------------|
| Density of the material              | $\rho$        | = | 2500 kg/m <sup>3</sup> |
| Thickness of the structure           | $d$           | = | 0.2 m                  |
| Loss factor                          | $\eta$        | = | 0.007                  |
| Material dependent constant          | $f_g * d$     | = | 17300 Hz * mm          |
| Calculations                         |               |   |                        |
| Mass                                 | $m$           | = | 500 kg/m <sup>2</sup>  |
| Higher threshold frequency           | $f_g$         | = | 87 Hz                  |
| Lower threshold frequency            | $f_1$         | = | 11 Hz                  |
| Increase in sound insulation         | $\Delta R$    | = | 17 dB                  |
| Sound insulation for $f_1 < f < f_g$ | $R_{plateau}$ | = | 44 dB                  |

## Appendix H Circularity assessment

### H.1 BCI method

#### Step 1: Bill of materials

First, information on the products and materials that make up the floor system is gathered into the bill of materials. The Bill of Materials (BOM) provides the input for the calculation of the different levels of circularity indicators.

For the different products in the floor system, the following information is gathered:

- The system lifetime associated with the product ( $L_{sys}$ ), based on the shearing layers by Brand (1994).  
*In the assessment of the floor systems, only the structural system is considered. The associated system lifetime of structural components is 100 years.*
- The length of the product's use phase ( $L_p$ )
- The sub-assemblies that make up the product

For the different sub-assemblies that make up the products, the following information is gathered:

- Mass ( $M$ )
- Non-virgin material input ( $NV$ )
- Reusable material input ( $F_{RU}$ )

#### Step 2: Material circularity indicator

The material input and output is calculated per square metre of floor surface.

##### Material input

The fraction of feedstock from virgin sources:

$$V_{(x)} = M_{(x)}(1 - NV_{RC(x)})$$

Where:

- $V_{(x)}$  is the fraction of feedstock for each subassembly [%]  
 $M_{(x)}$  is the total mass of the sub-assembly [%]  
 $NV_{RC(x)}$  is the fraction of feedstock from non-virgin sources for each sub-assembly [%]

The total virgin material input

$$V = \sum_x V_x$$

Where:

- $V$  is the total virgin material for a product [kg]

##### Material output

The total amount of waste:

$$W = M(1 - F_{RU})$$

Where:

- $W$  is the amount of waste of a product [%]  
 $M$  is the total mass of a product [%]  
 $F_{RU}$  is the fraction of a product that is reused, refurbished, remanufactured, and/or recycled [%]

##### Utility factor

$$X = \frac{L_p}{L_{sys}}$$

Where:

- $X$  is the utility factor of a product [-]  
 $L_p$  is the length of a product's use phase [years]  
 $L_{sys}$  is the building system lifetime [years]

### Linear flow index

$$LFI = \frac{(V + W)}{2M}$$

With  $0 \leq V \leq M$  and  $0 \leq W \leq M$  and the total mass flow equal to  $2M$

Where:

$LFI$  is the linear flow index of a product [-]

### Material Circularity Indicator

Function of the utility factor:

$$F(X) = \frac{0.9}{X}$$

Material Circularity Indicator:

$$MCI_p = \max(0; 1 - LFI_p * F(X_p))$$

Where:

$MCI_p$  is the material circularity indicator of a product [-]

### **Step 3: Product circularity indicator**

#### Disassembly factors

The disassembly potential of the product is assessed based on the weighted variables given in Table H.1.

Table H.1: Variable weights for disassembly factors (Verberne, 2016)

|                                            |                                                                      |            |
|--------------------------------------------|----------------------------------------------------------------------|------------|
| <b>Functional separation</b>               | Separation of functions                                              | <b>1,0</b> |
|                                            | Integration of function with same lifecycle into one element         | <b>0,6</b> |
|                                            | Integration of function with different lifecycle into one element    | <b>0,1</b> |
|                                            | Separation of functions                                              | <b>1,0</b> |
|                                            | Integration of function with same lifecycle into one element         | <b>0,6</b> |
| <b>Functional dependence</b>               | Modular zoning                                                       | <b>1,0</b> |
|                                            | Planned interpenetrating for different solutions (overcapacity)      | <b>0,8</b> |
|                                            | Planned for one solution                                             | <b>0,4</b> |
|                                            | Unplanned interpenetrating                                           | <b>0,2</b> |
|                                            | Total dependence                                                     | <b>0,1</b> |
| <b>Technical life cycle / coordination</b> | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | <b>1,0</b> |
|                                            | medium (1) / long (2)                                                | <b>0,5</b> |
|                                            | short (1) / medium (2)                                               | <b>0,3</b> |
|                                            | short (1) / long (2)                                                 | <b>0,1</b> |
| <b>Geometry of product edge</b>            | Open linear                                                          | <b>1,0</b> |
|                                            | Symmetrical overlapping                                              | <b>0,8</b> |
|                                            | Overlapping on one side                                              | <b>0,7</b> |
|                                            | Unsymmetrical overlapping                                            | <b>0,4</b> |
|                                            | Insert on one side                                                   | <b>0,2</b> |



|                                           |                                                                |     |
|-------------------------------------------|----------------------------------------------------------------|-----|
|                                           | Insert on two sides                                            | 0,1 |
| Standardisation of product edge           | Pre-made geometry                                              | 1,0 |
|                                           | Half standardised geometry                                     | 0,5 |
|                                           | Geometry made on the construction site                         | 0,1 |
| Type of connections                       | Accessory external connection or connection system             | 1,0 |
|                                           | Direct connection with additional fixing devices               | 0,8 |
|                                           | Direct integral connection with inserts (pin)                  | 0,6 |
|                                           | Direct integral connection                                     | 0,5 |
|                                           | Accessory internal connection                                  | 0,4 |
|                                           | Filled soft chemical connection                                | 0,2 |
|                                           | Filled hard chemical connection                                | 0,1 |
|                                           | Direct chemical connection                                     | 0,1 |
| Accessibility to fixings and intermediary | Accessible                                                     | 1,0 |
|                                           | Accessible with additional operation which causes no damage    | 0,8 |
|                                           | Accessible with additional operation which is reparable damage | 0,6 |
|                                           | Accessible with additional operation which causes damage       | 0,4 |
|                                           | Not accessible - total damage of bought elements               | 0,1 |

#### Product Circularity Indicator

$$PCI_p = \frac{1}{F_d} \sum_{i=1}^n MCI_p * F_i$$

Where:

$PCI_p$  is the product circularity indicator of a product [-]

$F_d$  is the maximum summation of disassembly factors possible (7.0) [-]

$F_i$  is the individual disassembly factor for each variable [-]

#### Step 4: System circularity indicator

Theoretical System Circularity Indicator (based on MCI):

$$SCI_{(t)} = \frac{1}{M_s} \sum_{j=1}^n MCI_j * M_j$$

Where:

$SCI_{(t)}$  is the theoretical system circularity indicator of a system [-]

$M_s$  is the mass of the system [kg]

$MCI_j$  is the material circularity indicator of a product j [-]

$M_j$  is the mass of a product j [kg]

## H.2 Current floor design

Table H.2: BOM current floor design

| Bill of Materials (BOM) |                |           |                   |                     |                                       |                 |                  |                 |
|-------------------------|----------------|-----------|-------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product        | Layer     | Use phase [years] | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P01001                  | Current design | Structure | 60                |                     | 500,0                                 | 500,0           | 0,0%             | 98,9%           |
|                         |                |           |                   | Reinforced concrete | 500                                   | 500             | 0,0%             | 98,9%           |

Table H.3: MCI current floor design

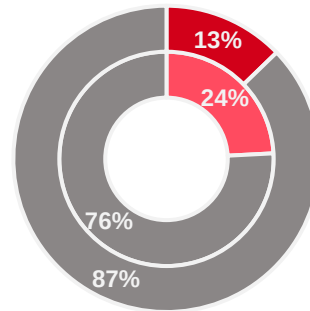
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P01001 Current design                |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 98,9%  | Linear flow index              | 0,51         |
| Waste material                       | 1,1%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,242</b> |

Table H.4: PCI current floor design

| Product Circularity Indicator (PCI)       |                                                                                                                    |                |                                   |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------|----------------|-----------------------------------|
| P01001 Current design                     |                                                                                                                    |                |                                   |
| Disassembly factors                       |                                                                                                                    | F <sub>i</sub> | MCI <sub>p</sub> * F <sub>i</sub> |
| Functional separation                     | Separation of functions is difficult, building services and load-bearing functions are integrated into one element | 0,1            | 0,024                             |
| Functional dependence                     | Total dependence                                                                                                   | 0,1            | 0,024                             |
| Technical life cycle / coordination       | The building services are cast into the load-bearing floor                                                         | 0,1            | 0,024                             |
| Geometry of product edge                  | Symmetrical overlapping                                                                                            | 0,8            | 0,193                             |
| Standardisation of product edge           | Pre-made geometry                                                                                                  | 1              | 0,242                             |
| Type of connections                       | Confidential                                                                                                       | 0,8            | 0,193                             |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage                                                        | 0,8            | 0,193                             |
|                                           |                                                                                                                    |                |                                   |
| Product circularity indicator             |                                                                                                                    |                |                                   |
| <b>PCI</b>                                | <b>0,128</b>                                                                                                       |                |                                   |

Table H.5: SCI current floor design

| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PCI   | MCI * M | PCI * M |
| P01001                             | 500,0 | 0,242 | 0,128 | 120,9   | 63,9    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,242 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,128 |       |       |         |         |



### H.3 Groove floors

Table H.6: BOM groove floors

| Bill of Materials (BOM) |               |           |                   |                      |                                       |                 |                  |                 |
|-------------------------|---------------|-----------|-------------------|----------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product       | Layer     | Use phase [years] | Materials            | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P02001                  | Groove floors | Structure | 60                |                      | 381,9                                 | 381,9           | 0,0%             | 99,0%           |
|                         |               |           |                   | Concrete             | 377                                   | 377             | 0%               | 99%             |
|                         |               |           |                   | Reinforce ment steel | 4,88                                  | 4,88            | 0%               | 99%             |

Table H.7: MCI groove floors

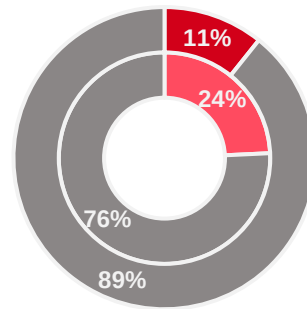
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P02001 Groove floors                 |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 99,0%  | Linear flow index              | 0,51         |
| Waste material                       | 1,0%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,243</b> |

Table H.8: PCI groove floors

| Product Circularity Indicator (PCI)       |       |                                                                                                                    |  |                |                                   |
|-------------------------------------------|-------|--------------------------------------------------------------------------------------------------------------------|--|----------------|-----------------------------------|
| P02001 Groove floors                      |       |                                                                                                                    |  |                |                                   |
| Disassembly factors                       |       |                                                                                                                    |  | F <sub>i</sub> | MCI <sub>p</sub> * F <sub>i</sub> |
| Functional separation                     |       | Separation of functions is difficult, building services and load-bearing functions are integrated into one element |  | 0,1            | 0,024                             |
| Functional dependence                     |       | The integration of functions is planned, but only for one situation                                                |  | 0,4            | 0,097                             |
| Technical life cycle / coordination       |       | Building services are cast into the load-bearing floor                                                             |  | 0,1            | 0,024                             |
| Geometry of product edge                  |       | Supported by a steel profile                                                                                       |  | 0,8            | 0,194                             |
| Standardisation of product edge           |       | Pre-made geometry                                                                                                  |  | 1              | 0,243                             |
| Type of connections                       |       | Filled with mortar                                                                                                 |  | 0,1            | 0,024                             |
| Accessibility to fixings and intermediary |       | Accessible with additional operation which is reparable damage                                                     |  | 0,6            | 0,146                             |
|                                           |       |                                                                                                                    |  |                |                                   |
| Product circularity indicator             |       |                                                                                                                    |  |                |                                   |
| PCI                                       | 0,107 |                                                                                                                    |  |                |                                   |

Table H.9: SCI groove floors

| System Circularity Indicator (SCI) |       |       |       |           |           |
|------------------------------------|-------|-------|-------|-----------|-----------|
| Product                            | Mass  | MCI   | PCI   | $MCI * M$ | $PCI * M$ |
| P02001                             | 381,9 | 0,243 | 0,107 | 92,6      | 41,0      |
|                                    |       |       |       |           |           |
| $SCI_t$                            | 0,243 |       |       |           |           |
| $SCI_p$                            | 0,107 |       |       |           |           |



#### H.4 CLC multifunctional floor system

Table H.10: BOM CLC floor

| Bill of Materials (BOM) |                    |           |                   |                     |                                       |                 |                  |                 |
|-------------------------|--------------------|-----------|-------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product            | Layer     | Use phase [years] | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P03001                  | Load-bearing floor | Structure | 60                |                     | 264,0                                 | 278,1           | 0,0%             | 99,1%           |
|                         |                    |           |                   | Reinforced concrete | 250                                   | 250             |                  |                 |
|                         |                    |           |                   | Steel beam          | 14,040                                | 28,08           |                  |                 |
| P03002                  | Top floor          | Structure | 60                |                     | 101,3                                 | 103,74          | 0,0%             | 91,3%           |
|                         |                    |           |                   | Concrete plates     | 92                                    | 92              | 0%               | 99%             |
|                         | (Octanorm, n.d.)   |           |                   | Adjustable feet     | 0,82                                  | 3,26            | 0%               | 100%            |

|  |  |  |  |                |      |      |    |    |
|--|--|--|--|----------------|------|------|----|----|
|  |  |  |  | Insulation mat | 0,18 | 0,18 | 0% | 5% |
|  |  |  |  | Plaster boards | 8,30 | 8,30 | 0% | 5% |

Table H.11: MCI CLC floor

| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P03001 Load-bearing floor            |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 99,1%  | Linear flow index              | 0,50         |
| Waste material                       | 0,9%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,243</b> |
| P03002 Top floor                     |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 91,3%  | Linear flow index              | 0,54         |
| Waste material                       | 8,7%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,185</b> |

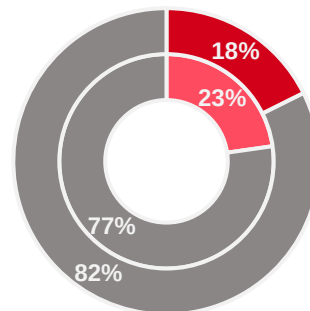
Table H.12: PCI CLC floor

| Product Circularity Indicator (PCI)       |                                                                      |       |               |
|-------------------------------------------|----------------------------------------------------------------------|-------|---------------|
| P03001 Load-bearing floor                 |                                                                      |       |               |
| Disassembly factors                       |                                                                      | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of load-bearing elements                                 | 0,6   | 0,146         |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      | 0,8   | 0,195         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1     | 0,243         |
| Geometry of product edge                  | Open linear                                                          | 1     | 0,243         |
| Standardisation of product edge           | Pre-made geometry                                                    | 1     | 0,243         |
| Type of connections                       | Connection is filled with concrete                                   | 0,1   | 0,024         |
| Accessibility to fixings and intermediary | Accessible with additional operation which is repairable damage      | 0,6   | 0,146         |
| Product circularity indicator             |                                                                      |       |               |

|                                           |                                                                      |  |                      |                                        |
|-------------------------------------------|----------------------------------------------------------------------|--|----------------------|----------------------------------------|
| <b>PCI</b>                                | <b>0,177</b>                                                         |  |                      |                                        |
| <b>P03002 Top floor</b>                   |                                                                      |  |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      |  | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Separation of functions                                              |  | 1                    | 0,185                                  |
| Functional dependence                     | Modular zoning                                                       |  | 1                    | 0,185                                  |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1                    | 0,185                                  |
| Geometry of product edge                  | Open linear                                                          |  | 1                    | 0,185                                  |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1                    | 0,185                                  |
| Type of connections                       | Direct connection with additional fixing devices                     |  | 0,8                  | 0,148                                  |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          |  | 0,8                  | 0,148                                  |
| <b>Product circularity indicator</b>      |                                                                      |  |                      |                                        |
| <b>PCI</b>                                | <b>0,175</b>                                                         |  |                      |                                        |

Table H.13: SCI CLC floor

| <b>System Circularity Indicator (SCI)</b> |              |       |       |         |         |
|-------------------------------------------|--------------|-------|-------|---------|---------|
| Product                                   | Mass         | MCI   | PCI   | MCI * M | PCI * M |
| P03001                                    | 278,1        | 0,243 | 0,177 | 67,6    | 49,3    |
| P03002                                    | 103,7        | 0,185 | 0,175 | 19,2    | 18,1    |
|                                           |              |       |       |         |         |
| <b>SCI<sub>t</sub></b>                    | <b>0,227</b> |       |       |         |         |
| <b>SCI<sub>p</sub></b>                    | <b>0,176</b> |       |       |         |         |



## H.5 Flexvloer

Table H.14: BOM Flexvloer

| <b>Bill of Materials (BOM)</b> |           |           |                   |                         |                           |                 |                  |                 |
|--------------------------------|-----------|-----------|-------------------|-------------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                            | Product   | Layer     | Use phase [years] | Materials               | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P04001                         | Flexvloer | Structure | 100               |                         | 33,7                      | 33,7            | 0,0%             | 11,8%           |
|                                |           |           |                   | Laminated veneer lumber | 30                        | 30              | 0%               | 1,0%            |
|                                |           |           |                   | Flax panels             | 3,68                      | 3,68            | 0%               | 100%            |



Table H.15: MCI Flexvloer

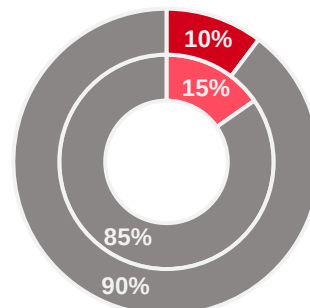
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P04001 Flexvloer                     |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 100          |
| Total                                | 100%   | Utility factor                 | 1,00         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 11,8%  | Linear flow index              | 0,94         |
| Waste material                       | 88,2%  |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 0,90         |
|                                      |        | <b>MCI</b>                     | <b>0,153</b> |

Table H.16: PCI Flexvloer

| Product Circularity Indicator (PCI)       |                                                                      |       |               |
|-------------------------------------------|----------------------------------------------------------------------|-------|---------------|
| P04001 Flexvloer                          |                                                                      |       |               |
| Disassembly factors                       |                                                                      | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6   | 0,092         |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      | 0,8   | 0,123         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1     | 0,153         |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8   | 0,123         |
| Standardisation of product edge           | Pre-made geometry                                                    | 1     | 0,153         |
| Type of connections                       | Glued connections                                                    | 0,1   | 0,015         |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes damage             | 0,4   | 0,061         |
|                                           |                                                                      |       |               |
| Product circularity indicator             |                                                                      |       |               |
| <b>PCI</b>                                | <b>0,103</b>                                                         |       |               |

Table H.17: SCI Flexvloer

| System Circularity Indicator (SCI) |              |       |       |           |           |
|------------------------------------|--------------|-------|-------|-----------|-----------|
| Product                            | Mass         | MCI   | PCI   | $MCI * M$ | $PCI * M$ |
| P04001                             | 33,7         | 0,153 | 0,103 | 5,2       | 3,5       |
|                                    |              |       |       |           |           |
| <b>SCI<sub>t</sub></b>             | <b>0,153</b> |       |       |           |           |
| <b>SCI<sub>p</sub></b>             | <b>0,103</b> |       |       |           |           |



## H.6 HOLCON floor

Table H.18: BOM HOLCON floor

| Bill of Materials (BOM) |                      |           |                   |                        |                                       |                 |                  |                 |
|-------------------------|----------------------|-----------|-------------------|------------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product              | Layer     | Use phase [years] | Materials              | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P05001                  | HOLCON floor         | Structure | 60                |                        | 602,0                                 | 608,9           | 0,0%             | 92,6%           |
|                         |                      |           |                   | Reinforced concrete    | 559                                   | 559             | 0%               | 99,1%           |
|                         |                      |           |                   | Lattice girders        | 0,983                                 | 7,862           | 0%               | 99,1%           |
|                         | (PBSHolland, n.d.-a) |           |                   | Calcium sulphate plate | 42                                    | 42              | 0%               | 5%              |

Table H.19: MCI HOLCON floor

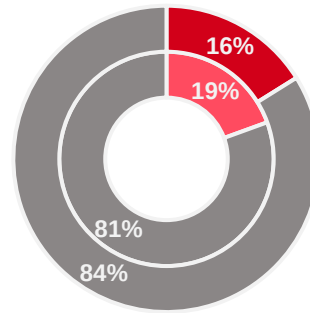
| Material Circularity Indicator (MCI) |        |                                       |              |
|--------------------------------------|--------|---------------------------------------|--------------|
| <b>P05001 HOLCON floor</b>           |        |                                       |              |
| <b>Material input</b>                |        | <b>Utility factor</b>                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials                     | 100,0% | Product's lifetime                    | 60           |
| Total                                | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>               |        | <b>Linear flow index</b>              |              |
| Reusable materials                   | 92,6%  | Linear flow index                     | 0,54         |
| Waste material                       | 7,4%   |                                       |              |
| Total                                | 100%   | <b>Material circularity indicator</b> |              |
|                                      |        | Function of the utility factor        | 1,50         |
|                                      |        | <b>MCI</b>                            | <b>0,195</b> |

Table H.20: PCI HOLCON floor

| Product Circularity Indicator (PCI)       |                                                                      |                      |                                        |
|-------------------------------------------|----------------------------------------------------------------------|----------------------|----------------------------------------|
| <b>P05001 HOLCON floor</b>                |                                                                      |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Integration of load-bearing elements                                 | 0,6                  | 0,117                                  |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      | 0,8                  | 0,156                                  |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1                    | 0,195                                  |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8                  | 0,156                                  |
| Standardisation of product edge           | Pre-made geometry                                                    | 1                    | 0,195                                  |
| Type of connections                       | Direct connection with additional fixing devices                     | 0,8                  | 0,156                                  |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          | 0,8                  | 0,156                                  |
| <b>Product circularity indicator</b>      |                                                                      |                      |                                        |
| <b>PCI</b>                                | <b>0,161</b>                                                         |                      |                                        |

Table H.21: SCI HOLCON floor

| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PCI   | MCI * M | PCI * M |
| P05001                             | 608,9 | 0,195 | 0,161 | 118,5   | 98,2    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,195 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,161 |       |       |         |         |



## H.7 Ides floor

Table H.22: BOM Ides floor

| Bill of Materials (BOM) |            |           |                   |           |                           |                 |                  |                 |
|-------------------------|------------|-----------|-------------------|-----------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product    | Layer     | Use phase [years] | Materials | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P06001                  | Ides floor | Structure | 80                |           | 50,0                      | 50,0            | 0,0%             | 99,0%           |
|                         |            |           |                   | Steel     | 50                        | 50              | 0%               | 99%             |

Table H.23: MCI Ides floor

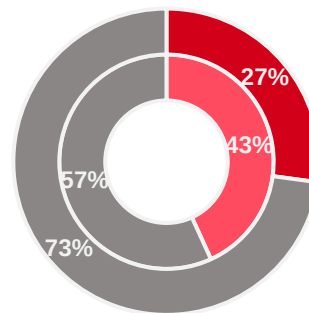
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P06001 Ides floor                    |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 80           |
| Total                                | 100%   | Utility factor                 | 0,80         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 99,0%  | Linear flow index              | 0,51         |
| Waste material                       | 1,0%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,13         |
|                                      |        | <b>MCI</b>                     | <b>0,432</b> |

Table H.24: PCI Ides floor

| Product Circularity Indicator (PCI)       |                                                                      |  |       |               |
|-------------------------------------------|----------------------------------------------------------------------|--|-------|---------------|
| P06001 Ides floor                         |                                                                      |  |       |               |
| Disassembly factors                       |                                                                      |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of function with same lifecycle into one element         |  | 0,6   | 0,259         |
| Functional dependence                     | Planned for one solution                                             |  | 0,4   | 0,173         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1     | 0,432         |
| Geometry of product edge                  | Insert on two sides                                                  |  | 0,1   | 0,043         |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1     | 0,432         |
| Type of connections                       | Direct integral connection                                           |  | 0,5   | 0,216         |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          |  | 0,8   | 0,346         |
| Product circularity indicator             |                                                                      |  |       |               |
| PCI                                       | 0,271                                                                |  |       |               |

Table H.25: SCI Ides floor

| System Circularity Indicator (SCI) |       |       |       |           |           |
|------------------------------------|-------|-------|-------|-----------|-----------|
| Product                            | Mass  | MCI   | PIC   | $MCI * M$ | $PCI * M$ |
| P06001                             | 50,0  | 0,432 | 0,271 | 21,6      | 13,6      |
|                                    |       |       |       |           |           |
| $SCI_t$                            | 0,432 |       |       |           |           |
| $SCI_p$                            | 0,271 |       |       |           |           |



## H.8 Lignatur floor

Table H.26: BOM Lignatur floor

| Bill of Materials (BOM) |          |           |                   |              |                           |                 |                  |                 |
|-------------------------|----------|-----------|-------------------|--------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product  | Layer     | Use phase [years] | Materials    | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P07001                  | Lignatur | Structure | 100               |              | 57,6                      | 57,6            | 0,0%             | 0,2%            |
|                         |          |           |                   | Wood         | 55,7                      | 55,7            | 0%               |                 |
|                         |          |           |                   | Glue         | 1,1                       | 1,1             | 0%               |                 |
|                         |          |           |                   | Mineral wool | 0,8                       | 0,8             | 0%               |                 |

Table H.27: MCI Lignatur floor

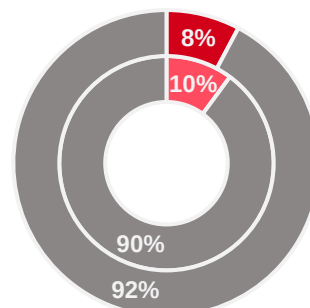
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P07001 Lignatur                      |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 100          |
| Total                                | 100%   | Utility factor                 | 1,00         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 0,2%   | Linear flow index              | 1,00         |
| Waste material                       | 99,8%  |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 0,90         |
|                                      |        | <b>MCI</b>                     | <b>0,101</b> |

Table H.28: PCI Lignatur floor

| Product Circularity Indicator (PCI)       |                                                                      |       |               |
|-------------------------------------------|----------------------------------------------------------------------|-------|---------------|
| P07001 Lignatur                           |                                                                      |       |               |
| Disassembly factors                       |                                                                      | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6   | 0,061         |
| Functional dependence                     | Planned for one solution                                             | 0,4   | 0,040         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1     | 0,101         |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8   | 0,081         |
| Standardisation of product edge           | Pre-made geometry                                                    | 1     | 0,101         |
| Type of connections                       | Direct connection with additional fixing devices                     | 0,8   | 0,081         |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          | 0,8   | 0,081         |
|                                           |                                                                      |       |               |
| Product circularity indicator             |                                                                      |       |               |
| <b>PCI</b>                                | <b>0,078</b>                                                         |       |               |

Table H.29: SCI Lignatur floor

| System Circularity Indicator (SCI) |              |       |       |           |           |
|------------------------------------|--------------|-------|-------|-----------|-----------|
| Product                            | Mass         | MCI   | PIC   | $MCI * M$ | $PCI * M$ |
| P07001                             | 57,6         | 0,101 | 0,078 | 5,8       | 4,5       |
|                                    |              |       |       |           |           |
| <b>SCI<sub>t</sub></b>             | <b>0,101</b> |       |       |           |           |
| <b>SCI<sub>p</sub></b>             | <b>0,078</b> |       |       |           |           |



## H.9 Slimline floor

Table H.30: BOM Slimline floor

| Bill of Materials (BOM) |          |                             |                   |                         |                           |                 |                  |                 |
|-------------------------|----------|-----------------------------|-------------------|-------------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product  | Layer                       | Use phase [years] | Materials               | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P08001                  | Slimline | Structure                   | 60                |                         | 320,3                     | 320,3           | 0,0%             | 95,7%           |
|                         |          |                             |                   | Concrete bottom slab    | 175,39                    | 175,39          | 0%               | 99,1%           |
|                         |          |                             |                   | IPE 240                 | 26,516                    | 26,516          | 0%               | 99,0%           |
|                         |          | (Intercodam Infra BV, 2015) |                   | Rubber granules         | 10,5                      | 10,5            | 0%               | 4,7%            |
|                         |          | (Reppel B.V., n.d.)         |                   | Trapizoidal sheet metal | 5,9144                    | 5,9144          | 0%               | 81,8%           |
|                         |          |                             |                   | Concrete top slab       | 102,0                     | 102,0           | 0%               | 99,1%           |

Table H.31: MCI Slimline floor

| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P08001 Slimline                      |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 95,7%  | Linear flow index              | 0,52         |
| Waste material                       | 4,3%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,218</b> |

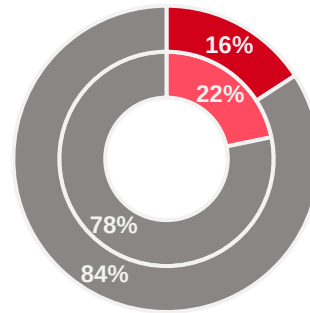
Table H.32: PCI Slimline floor

| Product Circularity Indicator (PCI)       |                                                                      |                |                                   |
|-------------------------------------------|----------------------------------------------------------------------|----------------|-----------------------------------|
| P08001 Slimline                           |                                                                      |                |                                   |
| Disassembly factors                       |                                                                      | F <sub>i</sub> | MCI <sub>p</sub> * F <sub>i</sub> |
| Functional separation                     | Integration of load-bearing elements                                 | 0,6            | 0,131                             |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      | 0,8            | 0,174                             |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1              | 0,218                             |
| Geometry of product edge                  | Open linear                                                          | 1              | 0,218                             |
| Standardisation of product edge           | Pre-made geometry                                                    | 1              | 0,218                             |
| Type of connections                       | Connection is filled with concrete                                   | 0,1            | 0,022                             |
| Accessibility to fixings and intermediary | Accessible with additional operation which is repairable damage      | 0,6            | 0,131                             |
|                                           |                                                                      |                |                                   |
| Product circularity indicator             |                                                                      |                |                                   |
| <b>PCI</b>                                | <b>0,159</b>                                                         |                |                                   |



Table H.33: SCI Slimline floor

| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P08001                             | 320,3 | 0,218 | 0,159 | 69,7    | 50,8    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,218 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,159 |       |       |         |         |



## H.10 Common floors for raised floor and suspended ceiling

Table H.34: BOM common floors

| Bill of Materials (BOM) |                                           |           |                   |                     |                           |                 |                  |                 |
|-------------------------|-------------------------------------------|-----------|-------------------|---------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product                                   | Layer     | Use phase [years] | Materials           | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P0X001                  | Cast in situ                              | Structure | 60                |                     | 615,0                     | 615,0           | 0,0%             | 98,9%           |
|                         |                                           |           |                   | Concrete            | 600                       | 600             | 0%               |                 |
|                         |                                           |           |                   | Reinforcement steel | 15,0                      | 15,0            | 0%               |                 |
| P0X002                  | Hollow core slab incl. structural topping | Structure | 60                |                     | 310,7                     | 919,56          | 0,0%             | 96%             |
|                         |                                           |           |                   | Concrete            | 303                       | 303             | 0%               |                 |
|                         |                                           |           |                   | Reinforcement steel | 7,7                       | 7,7             | 0%               |                 |
| P0X003                  | Hollow core slab excl. structural topping | Structure | 60                |                     | 305,9                     | 306             | 0,0%             | 99,0%           |
|                         |                                           |           |                   | Concrete            | 303                       | 303             | 0%               |                 |
|                         |                                           |           |                   | Reinforcement steel | 2,9                       | 2,86            | 0%               |                 |
| P0X004                  | Precast lattice slab                      | Structure | 60                |                     | 498,9                     | 498,9           | 0,0%             | 98,4%           |
|                         |                                           |           |                   | Concrete            | 480                       | 480             |                  |                 |
|                         |                                           |           |                   | Reinforcement steel | 18,9                      | 18,9            |                  |                 |

Table H.35: MCI common floors

| Material Circularity Indicator (MCI) |              |                    |      |
|--------------------------------------|--------------|--------------------|------|
| P0X001                               | Cast in situ |                    |      |
| Material input                       |              | Utility factor     |      |
| Non-virgin materials                 | 0,0%         | Layers' lifetime   | 100  |
| Virgin materials                     | 100,0%       | Product's lifetime | 60   |
| Total                                | 100%         | Utility factor     | 0,60 |

|                        |                                                  |                                       |              |
|------------------------|--------------------------------------------------|---------------------------------------|--------------|
|                        |                                                  |                                       |              |
| <b>Material output</b> |                                                  | <b>Linear flow index</b>              |              |
| Reusable materials     | 98,9%                                            | Linear flow index                     | 0,51         |
| Waste material         | 1,1%                                             |                                       |              |
| Total                  | 100%                                             | <b>Material circularity indicator</b> |              |
|                        |                                                  | Function of the utility factor        | 1,50         |
|                        |                                                  | <b>MCI</b>                            | <b>0,242</b> |
|                        |                                                  |                                       |              |
| <b>P0X002</b>          | <b>Hollow core slab incl. structural topping</b> |                                       |              |
| <b>Material input</b>  |                                                  | <b>Utility factor</b>                 |              |
| Non-virgin materials   | 0,0%                                             | Layers' lifetime                      | 100          |
| Virgin materials       | 100,0%                                           | Product's lifetime                    | 60           |
| Total                  | 100%                                             | Utility factor                        | 0,60         |
|                        |                                                  |                                       |              |
| <b>Material output</b> |                                                  | <b>Linear flow index</b>              |              |
| Reusable materials     | 96,0%                                            | Linear flow index                     | 0,52         |
| Waste material         | 4,1%                                             |                                       |              |
| Total                  | 100%                                             | <b>Material circularity indicator</b> |              |
|                        |                                                  | Function of the utility factor        | 1,50         |
|                        |                                                  | <b>MCI</b>                            | <b>0,220</b> |
|                        |                                                  |                                       |              |
| <b>P0X003</b>          | <b>Hollow core slab excl. structural topping</b> |                                       |              |
| <b>Material input</b>  |                                                  | <b>Utility factor</b>                 |              |
| Non-virgin materials   | 0,0%                                             | Layers' lifetime                      | 100          |
| Virgin materials       | 100,0%                                           | Product's lifetime                    | 60           |
| Total                  | 100%                                             | Utility factor                        | 0,60         |
|                        |                                                  |                                       |              |
| <b>Material output</b> |                                                  | <b>Linear flow index</b>              |              |
| Reusable materials     | 99,0%                                            | Linear flow index                     | 0,51         |
| Waste material         | 1,0%                                             |                                       |              |
| Total                  | 100%                                             | <b>Material circularity indicator</b> |              |
|                        |                                                  | Function of the utility factor        | 1,50         |
|                        |                                                  | <b>MCI</b>                            | <b>0,243</b> |
|                        |                                                  |                                       |              |
| <b>P0X004</b>          | <b>Precast lattice slab</b>                      |                                       |              |
| <b>Material input</b>  |                                                  | <b>Utility factor</b>                 |              |
| Non-virgin materials   | 0,0%                                             | Layers' lifetime                      | 100          |
| Virgin materials       | 100,0%                                           | Product's lifetime                    | 60           |
| Total                  | 100%                                             | Utility factor                        | 0,60         |
|                        |                                                  |                                       |              |
| <b>Material output</b> |                                                  | <b>Linear flow index</b>              |              |
| Reusable materials     | 98,4%                                            | Linear flow index                     | 0,51         |
| Waste material         | 1,6%                                             |                                       |              |
| Total                  | 100%                                             | <b>Material circularity indicator</b> |              |
|                        |                                                  | Function of the utility factor        | 1,50         |
|                        |                                                  | <b>MCI</b>                            | <b>0,238</b> |

Table H.36: PCI common floors

| Product Circularity Indicator (PCI)       |                                                                      |     |                      |                                        |
|-------------------------------------------|----------------------------------------------------------------------|-----|----------------------|----------------------------------------|
| <b>P0X001</b>                             | <b>Cast in situ</b>                                                  |     |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      |     | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6 | 0,145                |                                        |
| Functional dependence                     | Modular zoning                                                       | 1   | 0,242                |                                        |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1   | 0,242                |                                        |
| Geometry of product edge                  | Open linear                                                          | 1   | 0,242                |                                        |
| Standardisation of product edge           | Geometry made on the construction site                               | 0,1 | 0,024                |                                        |
| Type of connections                       | Direct chemical connection                                           | 0,1 | 0,024                |                                        |
| Accessibility to fixings and intermediary | Not accessible - total damage of bought elements                     | 0,1 | 0,024                |                                        |
| <b>Product circularity indicator</b>      |                                                                      |     |                      |                                        |
| <b>PCI</b>                                | <b>0,135</b>                                                         |     |                      |                                        |
|                                           |                                                                      |     |                      |                                        |
| <b>P0X002</b>                             | <b>Hollow core slab incl. structural topping</b>                     |     |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      |     | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6 | 0,132                |                                        |
| Functional dependence                     | Modular zoning                                                       | 1   | 0,220                |                                        |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1   | 0,220                |                                        |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8 | 0,176                |                                        |
| Standardisation of product edge           | Pre-made geometry                                                    | 1   | 0,220                |                                        |
| Type of connections                       | Filled hard chemical connection                                      | 0,1 | 0,022                |                                        |
| Accessibility to fixings and intermediary | Accessible with additional operation which is reparable damage       | 0,6 | 0,132                |                                        |
| <b>Product circularity indicator</b>      |                                                                      |     |                      |                                        |
| <b>PCI</b>                                | <b>0,160</b>                                                         |     |                      |                                        |
|                                           |                                                                      |     |                      |                                        |
| <b>P0X003</b>                             | <b>Hollow core slab excl. structural topping</b>                     |     |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      |     | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6 | 0,146                |                                        |
| Functional dependence                     | Modular zoning                                                       | 1   | 0,243                |                                        |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1   | 0,243                |                                        |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8 | 0,194                |                                        |
| Standardisation of product edge           | Pre-made geometry                                                    | 1   | 0,243                |                                        |
| Type of connections                       | Filled hard chemical connection                                      | 0,1 | 0,024                |                                        |
| Accessibility to fixings and intermediary | Accessible with additional operation which is reparable damage       | 0,6 | 0,146                |                                        |
| <b>Product circularity indicator</b>      |                                                                      |     |                      |                                        |
| <b>PCI</b>                                | <b>0,177</b>                                                         |     |                      |                                        |
|                                           |                                                                      |     |                      |                                        |
| <b>P0X004</b>                             | <b>Precast lattice slab</b>                                          |     |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      |     | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |

|                                           |                                                                      |     |       |
|-------------------------------------------|----------------------------------------------------------------------|-----|-------|
| Functional separation                     | Integration of function with same lifecycle into one element         | 0,6 | 0,143 |
| Functional dependence                     | Modular zoning                                                       | 1   | 0,238 |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1   | 0,238 |
| Geometry of product edge                  | Insert on two sides                                                  | 0,1 | 0,024 |
| Standardisation of product edge           | Half standardised geometry                                           | 0,5 | 0,119 |
| Type of connections                       | Direct chemical connection                                           | 0,1 | 0,024 |
| Accessibility to fixings and intermediary | Not accessible - total damage of bought elements                     | 0,1 | 0,024 |
| <b>Product circularity indicator</b>      |                                                                      |     |       |
| <b>PCI</b>                                | <b>0,116</b>                                                         |     |       |

Table H.37: SCI common floors

| System Circularity Indicator (SCI) |       |       |       |         |         |                  |                  |
|------------------------------------|-------|-------|-------|---------|---------|------------------|------------------|
| Product                            | Mass  | MCI   | PCI   | MCI * M | PCI * M | SCI <sub>t</sub> | SCI <sub>p</sub> |
| P0X001                             | 615,0 | 0,242 | 0,135 | 148,7   | 82,8    | 0,242            | 0,135            |
| P0X002                             | 919,6 | 0,219 | 0,160 | 201,6   | 146,9   | 0,219            | 0,160            |
| P0X003                             | 305,9 | 0,243 | 0,160 | 74,2    | 48,9    | 0,243            | 0,177            |
| P0X004                             | 498,9 | 0,238 | 0,106 | 118,7   | 53,1    | 0,238            | 0,116            |

## H.11 Raised floor

Table H.38: BOM raised floor

| Bill of Materials (BOM) |                  |          |                   |                     |                           |                 |                  |                 |
|-------------------------|------------------|----------|-------------------|---------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product          | Layer    | Use phase [years] | Materials           | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P08001                  | Raised floor     | Services | 25                |                     | 38,4                      | 42,3            | 0,0%             | 16,8%           |
|                         |                  |          |                   | Raised floor panels | 37                        | 37              | 0%               | 5%              |
|                         | (Octanorm, n.d.) |          |                   | Adjustable feet     | 0,82                      | 3,26            | 0%               | 100%            |
|                         |                  |          |                   | Frame               | 0,6                       | 2               | 0%               | 100%            |

Table H.39: MCI raised floor

| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P09001 Raised floor                  |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 15           |
| Virgin materials                     | 100,0% | Product's lifetime             | 25           |
| Total                                | 100%   | Utility factor                 | 1,67         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 16,8%  | Linear flow index              | 0,92         |
| Waste material                       | 83,2%  |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 0,54         |
|                                      |        | <b>MCI</b>                     | <b>0,505</b> |

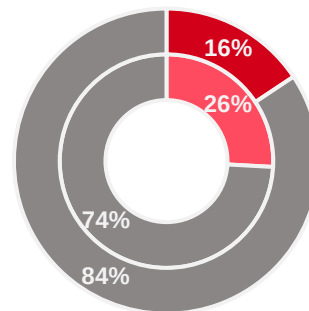
Table H.40: PCI raised floor

| Product Circularity Indicator (PCI)       |                                                                      |  |       |               |
|-------------------------------------------|----------------------------------------------------------------------|--|-------|---------------|
| P09001 Raised floor                       |                                                                      |  |       |               |
| Disassembly factors                       |                                                                      |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Separation of functions                                              |  | 1     | 0,505         |
| Functional dependence                     | Modular zoning                                                       |  | 1     | 0,505         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1     | 0,505         |
| Geometry of product edge                  | Symmetrical overlapping                                              |  | 0,8   | 0,404         |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1     | 0,505         |
| Type of connections                       | Direct connection with additional fixing devices                     |  | 0,8   | 0,404         |
| Accessibility to fixings and intermediary | Accessible                                                           |  | 1     | 0,505         |
| Product circularity indicator             |                                                                      |  |       |               |
| PCI                                       | 0,477                                                                |  |       |               |

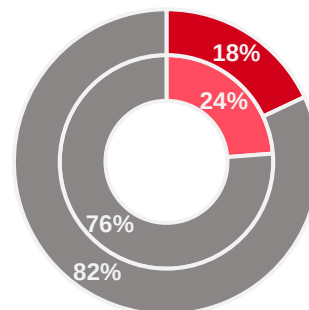
Table H.41: SCIs raised floor

| System Circularity Indicator (SCI) |      |       |       |           |           |         |         |
|------------------------------------|------|-------|-------|-----------|-----------|---------|---------|
| Product                            | Mass | MCI   | PCI   | $MCI * M$ | $PCI * M$ | $SCI_t$ | $SCI_p$ |
| P09001                             | 42,3 | 0,505 | 0,477 | 21,4      | 20,1      | 0,505   | 0,477   |

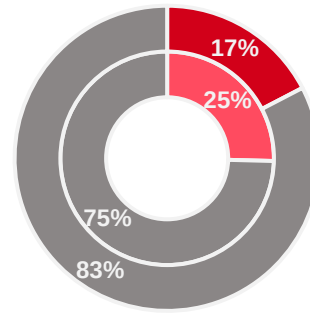
| System Circularity Indicator (SCI) |       |       |       |           |           |
|------------------------------------|-------|-------|-------|-----------|-----------|
| Product                            | Mass  | MCI   | PIC   | $MCI * M$ | $PCI * M$ |
| P09001                             | 42,3  | 0,505 | 0,477 | 21,4      | 20,1      |
| P0X001                             | 615,0 | 0,242 | 0,135 | 148,7     | 82,8      |
|                                    |       |       |       |           |           |
| $SCI_t$                            | 0,259 |       |       |           |           |
| $SCI_p$                            | 0,157 |       |       |           |           |



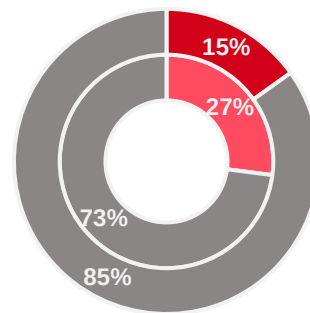
| System Circularity Indicator (SCI) |       |       |       |           |           |
|------------------------------------|-------|-------|-------|-----------|-----------|
| Product                            | Mass  | MCI   | PIC   | $MCI * M$ | $PCI * M$ |
| P09001                             | 42,3  | 0,505 | 0,477 | 21,4      | 20,1      |
| P0X002                             | 615,0 | 0,220 | 0,160 | 134,8     | 98,2      |
|                                    |       |       |       |           |           |
| $SCI_t$                            | 0,238 |       |       |           |           |
| $SCI_p$                            | 0,181 |       |       |           |           |



| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P09001                             | 42,3  | 0,505 | 0,477 | 21,4    | 20,1    |
| P0X003                             | 919,6 | 0,243 | 0,177 | 223,0   | 146,9   |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,254 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,190 |       |       |         |         |



| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P09001                             | 42,3  | 0,505 | 0,477 | 21,4    | 20,1    |
| P0X004                             | 305,9 | 0,238 | 0,116 | 72,8    | 32,6    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,270 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,159 |       |       |         |         |



## H.12 Suspended ceiling

Table H.42: BOM suspended ceiling

| Bill of Materials (BOM) |                   |          |                   |                     |                           |                 |                  |                 |
|-------------------------|-------------------|----------|-------------------|---------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product           | Layer    | Use phase [years] | Materials           | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P10001                  | Suspended ceiling | Services | 25                |                     | 2,3                       | 2,3             | 0,0%             | 23,2%           |
|                         |                   |          |                   | Mineral wool panels | 1,9                       | 1,9             | 0%               | 9,1%            |
|                         |                   |          |                   | Frame               | 0,40                      | 0,40            | 0%               | 90%             |



Table H.43: MCI suspended ceiling

| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P10001 Suspended ceiling             |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 15           |
| Virgin materials                     | 100,0% | Product's lifetime             | 25           |
| Total                                | 100%   | Utility factor                 | 1,67         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 23,2%  | Linear flow index              | 0,88         |
| Waste material                       | 76,8%  |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 0,54         |
|                                      |        | <b>MCI</b>                     | <b>0,523</b> |

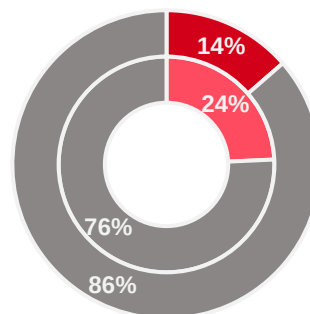
Table H.44: PCI suspended ceiling

| Product Circularity Indicator (PCI)       |                                                                      |       |               |
|-------------------------------------------|----------------------------------------------------------------------|-------|---------------|
| P10001 Suspended ceiling                  |                                                                      |       |               |
| Disassembly factors                       |                                                                      | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Separation of functions                                              | 1     | 0,523         |
| Functional dependence                     | Modular zoning                                                       | 1     | 0,523         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1     | 0,523         |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8   | 0,418         |
| Standardisation of product edge           | Pre-made geometry                                                    | 1     | 0,523         |
| Type of connections                       | Accessory external connection or connection system                   | 1     | 0,523         |
| Accessibility to fixings and intermediary | Accessible                                                           | 1     | 0,523         |
|                                           |                                                                      |       |               |
| Product circularity indicator             |                                                                      |       |               |
| <b>PCI</b>                                | <b>0,508</b>                                                         |       |               |

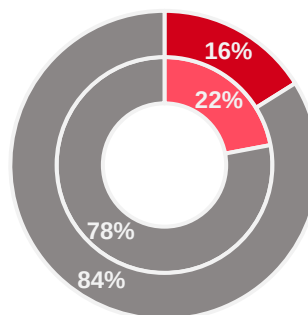
Table H.45: SCI suspended ceiling

| System Circularity Indicator (SCI) |      |       |       |           |           |         |         |
|------------------------------------|------|-------|-------|-----------|-----------|---------|---------|
| Product                            | Mass | MCI   | PCI   | $MCI * M$ | $PCI * M$ | $SCI_t$ | $SCI_p$ |
| P10001                             | 2,3  | 0,523 | 0,508 | 1,2       | 1,2       | 0,523   | 0,508   |

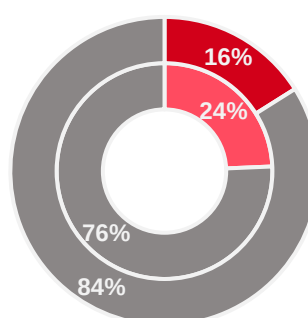
| System Circularity Indicator (SCI) |              |       |       |           |           |
|------------------------------------|--------------|-------|-------|-----------|-----------|
| Product                            | Mass         | MCI   | PCI   | $MCI * M$ | $PCI * M$ |
| P10001                             | 2,3          | 0,523 | 0,508 | 1,2       | 1,2       |
| P0X001                             | 615,0        | 0,242 | 0,135 | 148,7     | 82,8      |
|                                    |              |       |       |           |           |
| <b><math>SCI_t</math></b>          | <b>0,243</b> |       |       |           |           |
| <b><math>SCI_p</math></b>          | <b>0,136</b> |       |       |           |           |



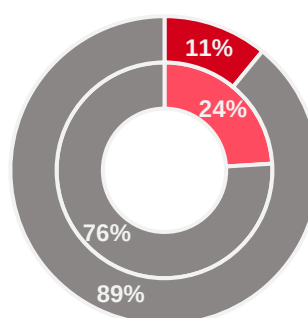
| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P10001                             | 2,3   | 0,523 | 0,508 | 1,2     | 1,2     |
| P0X002                             | 615,0 | 0,220 | 0,160 | 134,8   | 98,2    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,221 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,162 |       |       |         |         |



| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P10001                             | 2,3   | 0,523 | 0,508 | 1,2     | 1,2     |
| P0X003                             | 919,6 | 0,243 | 0,177 | 223,0   | 146,9   |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,243 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,178 |       |       |         |         |



| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P10001                             | 2,3   | 0,523 | 0,508 | 1,2     | 1,2     |
| P0X004                             | 305,9 | 0,238 | 0,116 | 72,8    | 32,6    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,240 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,119 |       |       |         |         |



### H.13 Hollow core slab

Table H.46: BOM Hollow core slab

| Bill of Materials (BOM) |                                           |           |                   |                     |                           |                 |                  |                 |
|-------------------------|-------------------------------------------|-----------|-------------------|---------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product                                   | Layer     | Use phase [years] | Materials           | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P11001                  | Hollow core slab incl. structural topping | Structure | 60                |                     | 310,7                     | 919,56          | 0,0%             | 96,0%           |
|                         |                                           |           |                   | Concrete            | 303                       | 303             | 0%               |                 |
|                         |                                           |           |                   | Reinforcement steel | 7,7                       | 7,7             | 0%               |                 |

Table H.47: MCI Hollow core slab

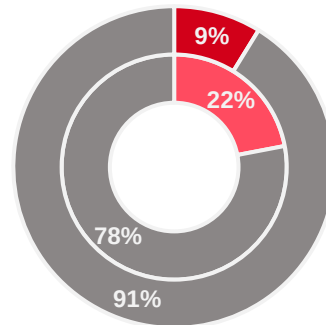
| Material Circularity Indicator (MCI)             |        |                                |              |
|--------------------------------------------------|--------|--------------------------------|--------------|
| P11001 Hollow core slab incl. structural topping |        |                                |              |
| Material input                                   |        | Utility factor                 |              |
| Non-virgin materials                             | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                                 | 100,0% | Product's lifetime             | 60           |
| Total                                            | 100%   | Utility factor                 | 0,60         |
|                                                  |        |                                |              |
| Material output                                  |        | Linear flow index              |              |
| Reusable materials                               | 96,0%  | Linear flow index              | 0,52         |
| Waste material                                   | 4,0%   |                                |              |
| Total                                            | 100%   | Material circularity indicator |              |
|                                                  |        | Function of the utility factor | 1,50         |
|                                                  |        | <b>MCI</b>                     | <b>0,220</b> |

Table H.48: PCI Hollow core slab

| Product Circularity Indicator (PCI)              |                                                                   |                |                                   |
|--------------------------------------------------|-------------------------------------------------------------------|----------------|-----------------------------------|
| P11001 Hollow core slab incl. structural topping |                                                                   |                |                                   |
| Disassembly factors                              |                                                                   | F <sub>i</sub> | MCI <sub>p</sub> * F <sub>i</sub> |
| Functional separation                            | Integration of function with different lifecycle into one element | 0,1            | 0,022                             |
| Functional dependence                            | Total dependence                                                  | 0,1            | 0,022                             |
| Technical life cycle / coordination              | short (1) / long (2)                                              | 0,1            | 0,022                             |
| Geometry of product edge                         | Symmetrical overlapping                                           | 0,8            | 0,176                             |
| Standardisation of product edge                  | Pre-made geometry                                                 | 1              | 0,220                             |
| Type of connections                              | Filled hard chemical connection                                   | 0,1            | 0,022                             |
| Accessibility to fixings and intermediary        | Accessible with additional operation which is repairable damage   | 0,6            | 0,132                             |
|                                                  |                                                                   |                |                                   |
| Product circularity indicator                    |                                                                   |                |                                   |
| <b>PCI</b>                                       | <b>0,088</b>                                                      |                |                                   |

Table H.49: SCI Hollow core slab

| System Circularity Indicator (SCI) |       |       |       |         |         |
|------------------------------------|-------|-------|-------|---------|---------|
| Product                            | Mass  | MCI   | PIC   | MCI * M | PCI * M |
| P11001                             | 919,6 | 0,220 | 0,088 | 202,3   | 80,9    |
|                                    |       |       |       |         |         |
| SCI <sub>t</sub>                   | 0,220 |       |       |         |         |
| SCI <sub>p</sub>                   | 0,088 |       |       |         |         |



## H.14 Precast lattice slab

Table H.50: BOM Precast lattice slab

| Bill of Materials (BOM) |                      |           |                   |                     |                           |                 |                  |                 |
|-------------------------|----------------------|-----------|-------------------|---------------------|---------------------------|-----------------|------------------|-----------------|
| Id#                     | Product              | Layer     | Use phase [years] | Materials           | Mass [kg/m2 or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P12001                  | Precast lattice slab | Structure | 60                |                     | 498,9                     | 498,9           | 0,0%             | 98,4%           |
|                         |                      |           |                   | Concrete            | 480                       | 480             |                  |                 |
|                         |                      |           |                   | Reinforcement steel | 18,9                      | 18,9            |                  |                 |

Tabel 1:

Table H.51: MCI Precast lattice slab

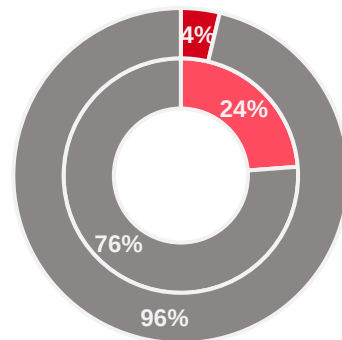
| Material Circularity Indicator (MCI) |        |                                |              |
|--------------------------------------|--------|--------------------------------|--------------|
| P12001 Precast lattice slab          |        |                                |              |
| Material input                       |        | Utility factor                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime               | 100          |
| Virgin materials                     | 100,0% | Product's lifetime             | 60           |
| Total                                | 100%   | Utility factor                 | 0,60         |
|                                      |        |                                |              |
| Material output                      |        | Linear flow index              |              |
| Reusable materials                   | 98,4%  | Linear flow index              | 0,51         |
| Waste material                       | 1,6%   |                                |              |
| Total                                | 100%   | Material circularity indicator |              |
|                                      |        | Function of the utility factor | 1,50         |
|                                      |        | <b>MCI</b>                     | <b>0,238</b> |

Table H.52: PCI Precast lattice slab

| Product Circularity Indicator (PCI)       |                                                                   |  |       |               |
|-------------------------------------------|-------------------------------------------------------------------|--|-------|---------------|
| P12001 Precast lattice slab               |                                                                   |  |       |               |
| Disassembly factors                       |                                                                   |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of function with different lifecycle into one element |  | 0,1   | 0,024         |
| Functional dependence                     | Total dependence                                                  |  | 0,1   | 0,024         |
| Technical life cycle / coordination       | short (1) / long (2)                                              |  | 0,1   | 0,024         |
| Geometry of product edge                  | Insert on two sides                                               |  | 0,1   | 0,024         |
| Standardisation of product edge           | Half standardised geometry                                        |  | 0,5   | 0,119         |
| Type of connections                       | Direct chemical connection                                        |  | 0,1   | 0,024         |
| Accessibility to fixings and intermediary | Not accessible - total damage of bought elements                  |  | 0,1   | 0,024         |
| Product circularity indicator             |                                                                   |  |       |               |
| PCI                                       | 0,037                                                             |  |       |               |

Tabel 2: SCI Precast lattice slab

| System Circularity Indicator (SCI) |       |       |       |           |           |
|------------------------------------|-------|-------|-------|-----------|-----------|
| Product                            | Mass  | MCI   | PIC   | $MCI * M$ | $PIC * M$ |
| P12001                             | 498,9 | 0,238 | 0,037 | 118,7     | 18,7      |
|                                    |       |       |       |           |           |
| $SCI_t$                            | 0,238 |       |       |           |           |
| $SCI_p$                            | 0,037 |       |       |           |           |

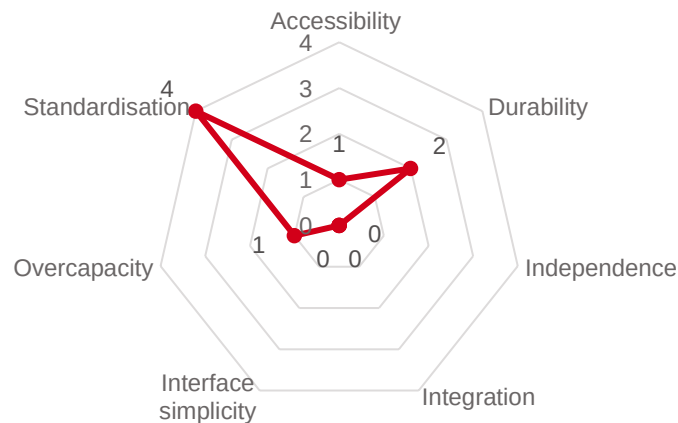


## Appendix I Flexibility assessment

### I.1 Current floor design

Table I.1: Flexibility assessment current floor design

| Flexibility characteristic | Weight | Input                                                                                                                   |                              | Score |      | Comments                                                                                                                                                                                                                                                                           |
|----------------------------|--------|-------------------------------------------------------------------------------------------------------------------------|------------------------------|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through damaging operation, not affecting functionality                                                      |                              | 1     | 0,19 | This is an assumption. The degree of damage is dependent on the size and positioning of the elements that need to be accessed. Likely some adaptations can be done through operations resulting in reparable damage while other larger adaptations could affect the functionality. |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                               |                              | 2     | 0,24 | Based on (Dias, 2003)                                                                                                                                                                                                                                                              |
| Independence               | 0,146  | No zoning, fully combined                                                                                               |                              | 0     | 0,00 | Building services are cast into the floor with no specific zoning                                                                                                                                                                                                                  |
| Integration                | 0,093  | None of the components that are not reasonably expected to be adapted separately are integrated into separate elements. |                              | 0     | 0,00 | The floor consists of one element with no separation based on functioning or service life.                                                                                                                                                                                         |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                |                              | 0     | 0,00 | The building services are cast into the floor, so a cement bonding connection                                                                                                                                                                                                      |
| Overcapacity               | 0,167  | No surplus                                                                                                              | 2.55 - 3.8 kN/m <sup>2</sup> | 1     | 0,17 | No surplus space for building services, as the building services take up a height of up to 168 mm and the floor is 200 mm high, including a 15 mm concrete cover. The load-bearing capacity is assumed based on the use in residential buildings.                                  |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                   |                              | 4     | 0,52 | There are no different parts and thus no different connections or sizing. A single type of connection is assumed for the connection of the floor elements.                                                                                                                         |
|                            |        |                                                                                                                         |                              |       | 1,11 |                                                                                                                                                                                                                                                                                    |

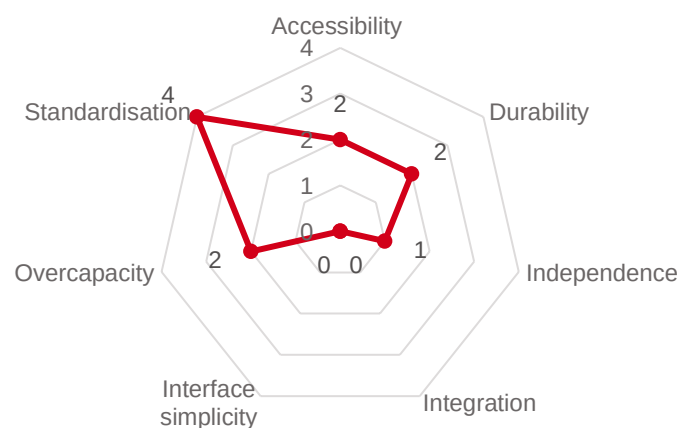




## I.2 Dycore and VBI piping floors

Table I.2: Flexibility assessment piping floors

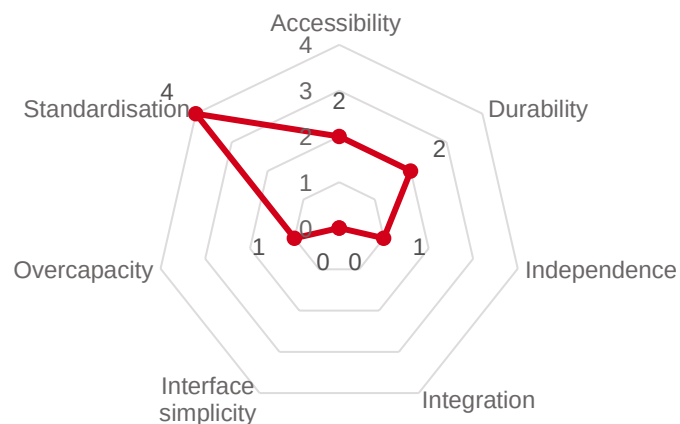
| Flexibility characteristic | Weight | Input                                                                                                                   |                  | Score |      | Comments                                                                                                                                                                                                                                                   |
|----------------------------|--------|-------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through operation resulting in reparable damage                                                              |                  | 2     | 0,37 | The piping is placed in predetermined grooves and can be accessed by cutting through the screed at these locations.                                                                                                                                        |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                               |                  | 2     | 0,24 | Based on (Dias, 2003)                                                                                                                                                                                                                                      |
| Independence               | 0,146  | Interconnected zoning of functions                                                                                      |                  | 1     | 0,15 | The different functions have their own place within the system, but the grooves are usually filled with mortar resulting in full interconnection.                                                                                                          |
| Integration                | 0,093  | None of the components that are not reasonably expected to be adapted separately are integrated into separate elements. |                  | 0     | 0,00 | The floor consists of one element with no separate parts.                                                                                                                                                                                                  |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                |                  | 0     | 0,00 | Usually bonded with cement, both between building services and load-bearing structure and between floor elements.                                                                                                                                          |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                        | 2.55 - 3.8 kN/m2 | 2     | 0,33 | Extra grooves can be added in production to create overcapacity for the building services. The grooves are limited to specific locations in the floor. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                   |                  | 4     | 0,52 | There are no different parts and thus no different connections or sizing. A single type of connection is assumed for the connection of the floor elements.                                                                                                 |
|                            |        |                                                                                                                         |                  |       | 1,61 |                                                                                                                                                                                                                                                            |



### I.3 Wing floor

Table I.3: Flexibility assessment wing floor

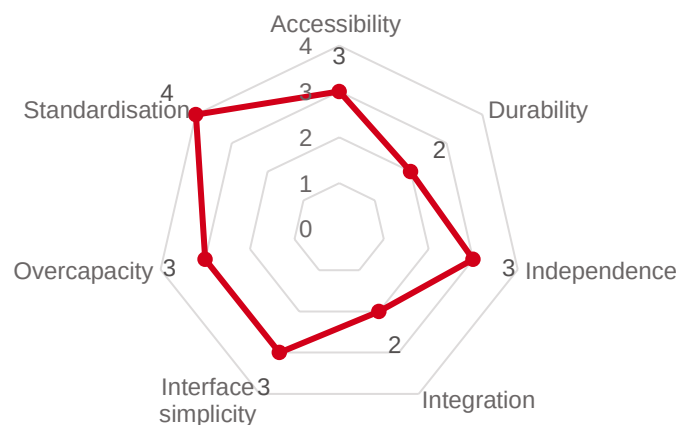
| Flexibility characteristic | Weight | Input                                                                                                                   |                  | Score |      | Comments                                                                                                                                                                                                                                         |
|----------------------------|--------|-------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through operation resulting in reparable damage                                                              |                  | 2     | 0,37 | The piping is placed in the channels created by the wings of the floor elements and can be accessed by cutting through the screed at these locations.                                                                                            |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                               |                  | 2     | 0,24 | Based on (Dias, 2003)                                                                                                                                                                                                                            |
| Independence               | 0,146  | Interconnected zoning of functions                                                                                      |                  | 1     | 0,15 | The different functions have their own place within the system, but the grooves are usually filled with mortar resulting in full interconnection.                                                                                                |
| Integration                | 0,093  | None of the components that are not reasonably expected to be adapted separately are integrated into separate elements. |                  | 0     | 0,00 | The floor consists of one element with no separate parts.                                                                                                                                                                                        |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                |                  | 0     | 0,00 | Usually bonded with cement, both between building services and load-bearing structure and between floor elements.                                                                                                                                |
| Overcapacity               | 0,167  | No surplus                                                                                                              | 2.55 - 3.8 kN/m2 | 1     | 0,17 | There is no surplus space for building services in the transverse direction. Any remaining space in the wing grooves could be surplus space. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                   |                  | 4     | 0,52 | There are no different parts and thus no different connections or sizing. A single type of connection is assumed for the connection of the floor elements.                                                                                       |
|                            |        |                                                                                                                         |                  |       | 1,44 |                                                                                                                                                                                                                                                  |



## I.4 CLC multifunctional floor system

Table I.4: Flexibility assessment CLC floor

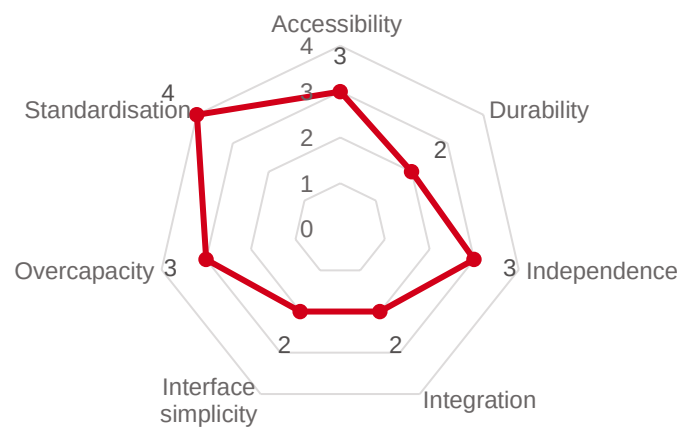
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                                                                                    |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                  | 3     | 0,56 | The building services inside the floor can be accessed through the plasterboards screwed on top.                                                                                                                                                                                                                            |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                  | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                      |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                  | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                                 |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                  |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                  | 3     | 0,48 | The elements are connected through either dry or screwed connections, with exception of the concrete and steel connection which is a hard chemical connection using cement. As a separate adaption is not reasonably expected, this connection is not considered.                                                           |
| Overcapacity               | 0,167  | ≥ 50% surplus                                                                                                                                                 | 2.55 - 3.8 kN/m2 | 3     | 0,50 | The hollow space has a height of 180 to 500 mm, depending on the floor height. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web openings. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | All the connection details are standardised and a standardised system width is used.                                                                                                                                                                                                                                        |
|                            |        |                                                                                                                                                               |                  |       | 2,92 |                                                                                                                                                                                                                                                                                                                             |



## I.5 Con4 floor

Table I.5: Flexibility assessment Con4 floor

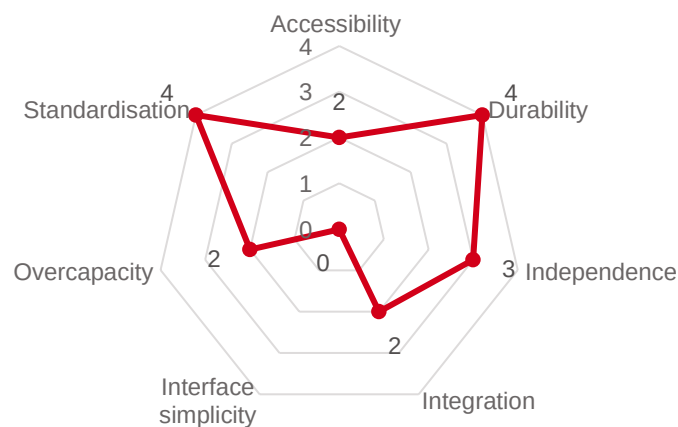
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                 | Score |      | Comments                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                 | 3     | 0,56 | Accessibility through inspection openings in the top floor slab. The type of opening is not specified, a non-damaging operation is assumed.                                                                                                                                                                                                                                                                                                                         |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                 | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                 | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                                                                                                                                                                         |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                 | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                                                                                                                                                          |
| Interface simplicity       | 0,160  | Direct integral connection                                                                                                                                    |                 | 2     | 0,32 | No detailed information on the connections is available. The building services within the floor are not assumed to be connected to the structure. The inspection openings are assumed to be accessible through non-damaging operations (connections with added elements or integral connections). The connection of the concrete and steel is a hard connection using cement, as a separate adaption is not reasonably expected, this connection is not considered. |
| Overcapacity               | 0,167  | 30 - 50% surplus                                                                                                                                              | 3.8 - 6.2 kN/m2 | 3     | 0,50 | The hollow space has a height of 200 mm. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web openings. A high load-bearing overcapacity is assumed as the floor has a fixed floor height and can reach a span of 16 m, likely resulting in overcapacity for spans commonly used in residential buildings.                                                                                |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                 | 4     | 0,52 | There is only one element size. It is assumed that no different types of connections are used.                                                                                                                                                                                                                                                                                                                                                                      |
|                            |        |                                                                                                                                                               |                 |       | 2,76 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |



## I.6 Flexvloer

Table I.6: Flexibility assessment Flexvloer

| Flexibility characteristic | Weight | Input                                                                                                                                                         | Score |             | Comments                                                                                                                                                                                                                                                                                                               |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through operation resulting in reparable damage                                                                                                    | 2     | 0,37        | Accessibility from both the top and the bottom. Glue is used in the connection of the top and bottom slabs, therefore cutting is assumed to be required for accessibility.                                                                                                                                             |
| Durability                 | 0,119  | High design life ( $\geq 100$ years), requiring a modest level of maintenance                                                                                 | 4     | 0,48        | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                 |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         | 3     | 0,44        | The building services have their own space within the floor. The timber ribs contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                            |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system | 2     | 0,19        | The timber slabs and ribs are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                     |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                                                      | 0     | 0,00        | The different elements that make up the floor are glued together. It is assumed that the building services inside the floor are not connected to the timber.                                                                                                                                                           |
| Overcapacity               | 0,167  | 30 - 50% surplus $\geq 2.25$ kN/m <sup>2</sup>                                                                                                                | 2     | 0,33        | The floor has a total height of 385 mm. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web openings. The floor has a load-bearing capacity of only 1.7 kN/m <sup>2</sup> , which is lower than the minimum used in this assessment method. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         | 4     | 0,52        | There is only one element size. It is assumed that no different types of connections are used.                                                                                                                                                                                                                         |
|                            |        |                                                                                                                                                               |       | <b>2,33</b> |                                                                                                                                                                                                                                                                                                                        |

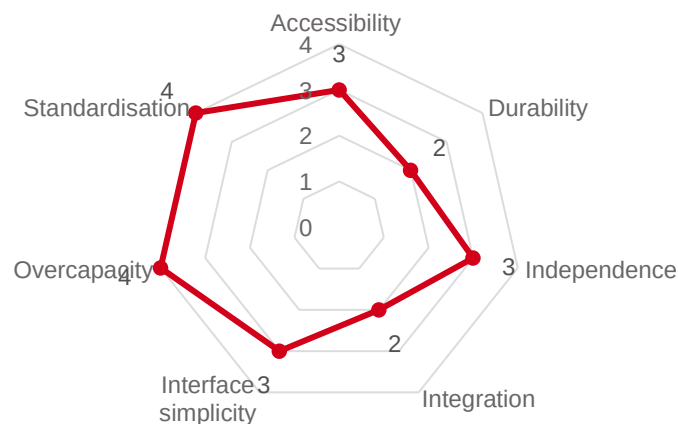




## I.7 HOLCON floor

Table I.7: Flexibility assessment HOLCON floor

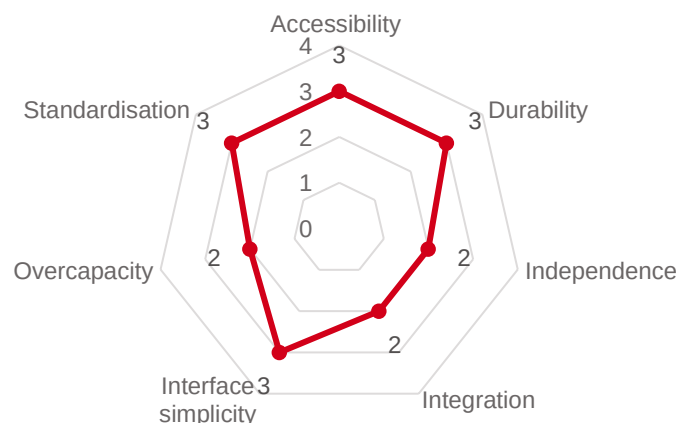
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                 | Score |      | Comments                                                                                                                                                                                                                                                                                                                            |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                 | 3     | 0,56 | The top slab is 50 cm less wide to ensure accessibility. The gaps are closed using calcium sulphate plates. A non-damaging operation is assumed to remove this plate.                                                                                                                                                               |
| Durability                 | 0,119  | Minimum design life ( $\geq 50$ years), requiring a modest level of maintenance                                                                               |                 | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                              |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                 | 3     | 0,44 | The building services have their own space within the floor. The lattice girders are spatially open and allow piping to be laid through, this is an intentional interconnection.                                                                                                                                                    |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                 | 2     | 0,19 | The concrete slabs and lattice girders are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                     |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                 | 3     | 0,48 | Steel anchor plates are embedded in the floor for the connections between elements                                                                                                                                                                                                                                                  |
| Overcapacity               | 0,167  | $\geq 50\%$ surplus                                                                                                                                           | 3.8 - 6.2 kN/m2 | 4     | 0,67 | The floor has a hollow space of 440 mm. The entire floor surface can be used for the distribution of the building services. A high load-bearing overcapacity is assumed as the floor has a fixed floor height and can reach a span of 18 m, likely resulting in overcapacity for spans more commonly used in residential buildings. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                 | 4     | 0,52 | There is only one element size. It is assumed that no different types of connections are used.                                                                                                                                                                                                                                      |
|                            |        |                                                                                                                                                               |                 |       | 3,09 |                                                                                                                                                                                                                                                                                                                                     |



## I.8 Ides floor

Table I.8: Flexibility assessment Ides floor

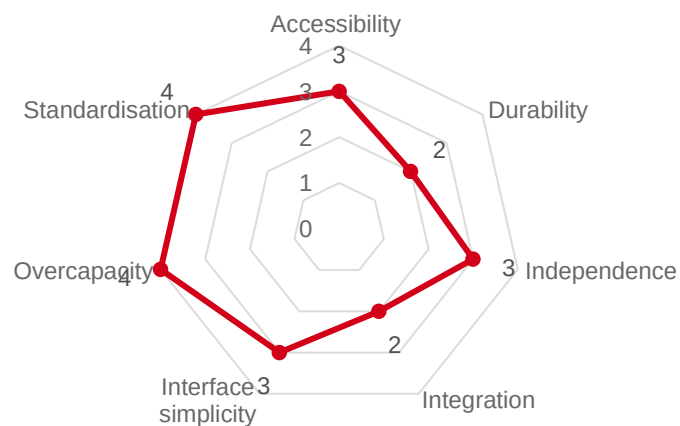
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                                                                 |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                  | 3     | 0,56 | Accessibility through hatches or grates in the creed. The type of opening is not specified, a non-damaging operation is assumed.                                                                                                                                                                         |
| Durability                 | 0,119  | Intermediate design life (≥ 75 years), requiring a modest level of maintenance                                                                                |                  | 3     | 0,36 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                   |
| Independence               | 0,146  | Zoning of functions, partial interconnection                                                                                                                  |                  | 2     | 0,29 | The building services have their own space within the floor. Openings in the webs can be added at some specific locations if needed. This is partial interconnection, not fully intentional in the design.                                                                                               |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The steel elements are integrated into a single technical element but are still demountable.                                                                                                                                                                                                             |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                  | 3     | 0,48 | The floor system is fully demountable. It is assumed that the connections use added elements.                                                                                                                                                                                                            |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                                                              | 2.55 - 3.8 kN/m2 | 2     | 0,33 | The hollow space has a height of 250 to 400 mm, depending on the floor height. There are possibilities for limited openings in the webs to spread the building services over the floor surface area. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | 2 types of details and/or sizing used                                                                                                                         |                  | 3     | 0,39 | The floor consists of separate steel elements, therefore it is assumed that more than one type of connection is used.                                                                                                                                                                                    |
|                            |        |                                                                                                                                                               |                  |       | 2,60 |                                                                                                                                                                                                                                                                                                          |



## I.9 InaDeck

Table I.9: Flexibility assessment InaDeck

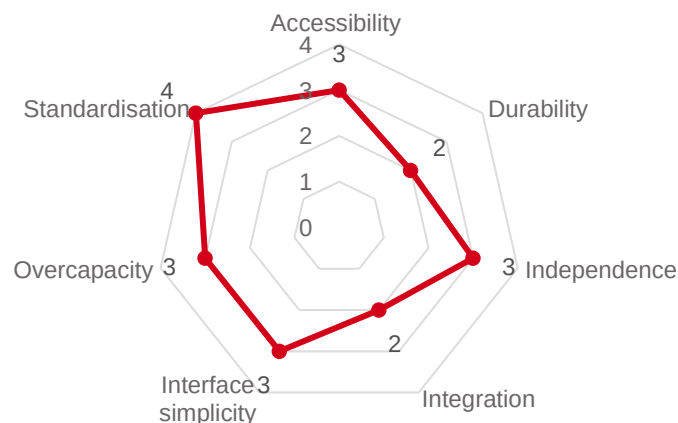
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                 | Score |      | Comments                                                                                                                                                                                                                                                      |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                 | 3     | 0,56 | Removable panel elements are placed on top of the I-profile. It is assumed a non-damaging operation is required for accessibility                                                                                                                             |
| Durability                 | 0,119  | Minimum design life ( $\geq 50$ years), requiring a modest level of maintenance                                                                               |                 | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                        |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                 | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                   |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                 | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                    |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                 | 3     | 0,48 | The screed is assumed to use screws or other fasteners. The concrete and steel connection which is a hard chemical connection using cement, as a separate adaption is not reasonably expected, this connection is not considered.                             |
| Overcapacity               | 0,167  | $\geq 50\%$ surplus                                                                                                                                           | 3.8 - 6.2 kN/m2 | 4     | 0,67 | The floor has a height of approximately 500 mm. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web openings. The floor has a load-bearing capacity of up to 5 kN/m <sup>2</sup> . |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                 | 4     | 0,52 | It is assumed that no different types of connections are used.                                                                                                                                                                                                |
|                            |        |                                                                                                                                                               |                 |       | 3,09 |                                                                                                                                                                                                                                                               |



## I.10 Infra+ floor

Table I.10: Flexibility assessment Infra+ floor

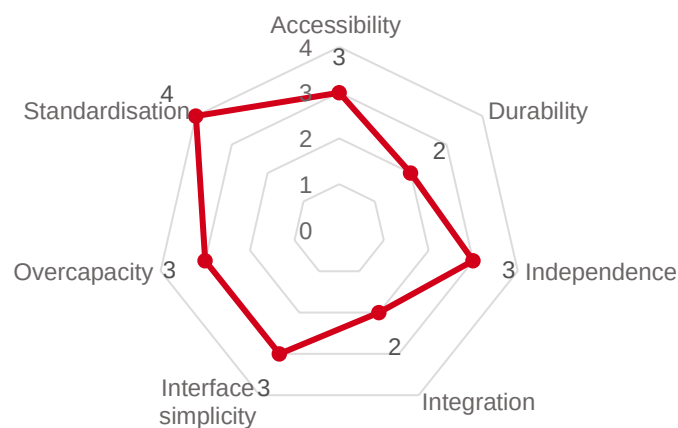
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                                                                                                              |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                  | 2     | 0,37 | The accessibility depends on the screed used. If a demountable plate is used as recommended, accessibility is realised through a non-damaging operation. If a screed is applied, reparable damage is required for accessibility. The second option is assumed.                                                                                        |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                  | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                                                |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                  | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                                                           |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                                            |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                  | 0     | 0,00 | The different parts of the floor are cast into place, the cement bond is a hard chemical connection                                                                                                                                                                                                                                                   |
| Overcapacity               | 0,167  | 30 - 50% surplus                                                                                                                                              | 2.55 - 3.8 kN/m2 | 3     | 0,50 | The hollow space height depends on the floor height chosen, no specific information is available on this. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web opening. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | There is only one element width. It is assumed that no different types of connections are used.                                                                                                                                                                                                                                                       |
|                            |        |                                                                                                                                                               |                  |       | 2,26 |                                                                                                                                                                                                                                                                                                                                                       |



## I.11 Floor system developed by TU Wien

Table I.11: Flexibility assessment TU Wien floor

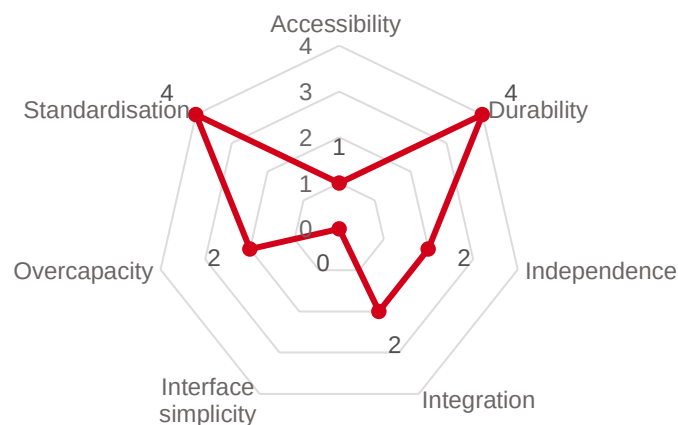
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                 | Score |      | Comments                                                                                                                                                                                                                                                                                                                                                         |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                 | 3     | 0,56 | Accessibility through a removable screed. It is assumed a non-damaging operation is required for accessibility                                                                                                                                                                                                                                                   |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                 | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                                                           |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                 | 3     | 0,44 | The building services have their own space within the floor. The concrete frame contains through which piping can be laid, this is an intentional interconnection.                                                                                                                                                                                               |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                 | 2     | 0,19 | The concrete elements that make up the structural floor are integrated into a single technical element and are not reasonably expected to be adapted separately                                                                                                                                                                                                  |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                 | 3     | 0,48 | The screed is assumed to use screws or other fasteners. The concrete connections are hard chemical connections using cement, as a separate adaption is not reasonably expected, these connections are not considered.                                                                                                                                            |
| Overcapacity               | 0,167  | 30 - 50% surplus                                                                                                                                              | 3.8 - 6.2 kN/m2 | 3     | 0,50 | The floor is 900 mm high. The surplus space for building services is slightly hindered by the concrete framework between the top and bottom slabs. A high load-bearing overcapacity is assumed as the floor has a fixed floor height and can reach a span of up to 16 m, likely resulting in overcapacity for spans more commonly used in residential buildings. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                 | 4     | 0,52 | There is only one element size. It is assumed that no different types of connections are used.                                                                                                                                                                                                                                                                   |
|                            |        |                                                                                                                                                               |                 |       | 2,92 |                                                                                                                                                                                                                                                                                                                                                                  |



## I.12 Lignatur

Table I.12: Flexibility assessment Lignatur

| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                           |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through damaging operation, not affecting functionality                                                                                            |                  | 1     | 0,19 | The building services are placed within the hollow channels. These need to be cut open for accessibility                                                                                                                                                           |
| Durability                 | 0,119  | High design life (≥ 100 years), requiring a modest level of maintenance                                                                                       |                  | 4     | 0,48 | Based on (Dias, 2003).                                                                                                                                                                                                                                             |
| Independence               | 0,146  | Zoning of functions, partial interconnection                                                                                                                  |                  | 2     | 0,29 | The building services have their own space within the floor. Openings of a small diameter can be made for the placement of piping in the transversal direction. This is partial interconnection, not fully intentional in the design.                              |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The timber elements are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                       |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                                                      |                  | 0     | 0,00 | The different elements that make up the floor are glued together. It is assumed that the building services inside the floor are not connected to the timber.                                                                                                       |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                                                              | 2.55 - 3.8 kN/m2 | 2     | 0,33 | The floor has a height of 120 to 320 mm. There are possibilities for limited openings in the webs to spread the building services over the floor surface area. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | There are no different parts and thus no different connections or sizing. A single type of connection is assumed for the connection of the floor elements.                                                                                                         |
|                            |        |                                                                                                                                                               |                  |       | 1,99 |                                                                                                                                                                                                                                                                    |

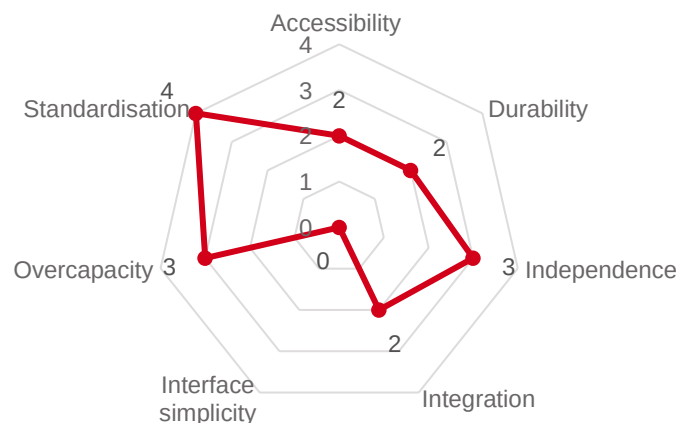




### I.13 Slimline floor

Table I.13: Flexibility assessment Slimline floor

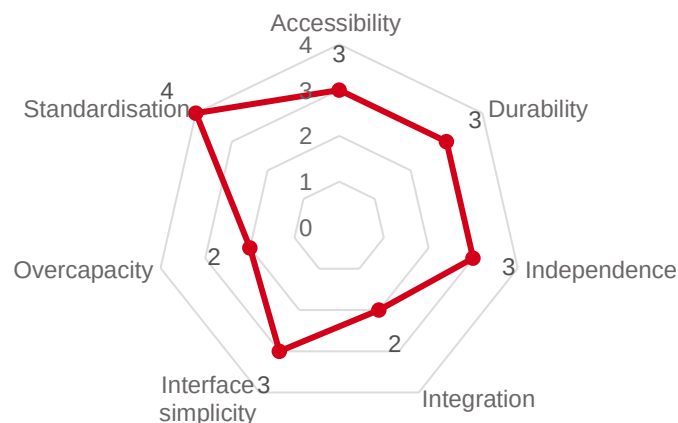
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                                                             |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through operation resulting in reparable damage                                                                                                    |                  | 2     | 0,37 | Accessible through the screed, not specifically demountable. Can be cut where needed                                                                                                                                                                                                                 |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                  | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                               |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                  | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                          |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                           |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                                                      |                  | 0     | 0,00 | The different parts of the floor are cast into place, the cement bond is a hard chemical connection                                                                                                                                                                                                  |
| Overcapacity               | 0,167  | ≥ 50% surplus                                                                                                                                                 | 2.55 - 3.8 kN/m2 | 3     | 0,50 | The floor has a height of up to 720 mm including screed. The entire floor surface can be used for the distribution of the building services, taking into account the spacing of the web opening. The load-bearing overcapacity depends on the floor height chosen, a normal overcapacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | A single type of connection is assumed for the connection of the floor elements.                                                                                                                                                                                                                     |
|                            |        |                                                                                                                                                               |                  |       | 2,26 |                                                                                                                                                                                                                                                                                                      |



## I.14 Starframe floor

Table I.14: Flexibility assessment Starframe floor

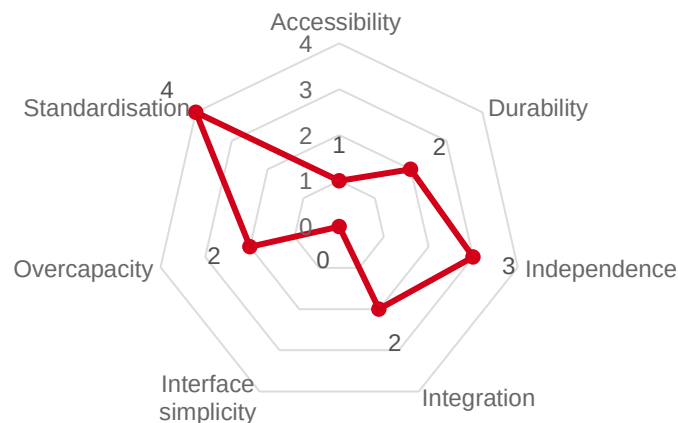
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through non-damaging operation                                                                                                                     |                  | 3     | 0,56 | Accessible through gypsum cardboard panels fastened with screws at the bottom side                                                                                                                                                                                                                                                                                                 |
| Durability                 | 0,119  | Intermediate design life (≥ 75 years), requiring a modest level of maintenance                                                                                |                  | 3     | 0,36 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                                                                             |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                  | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                                                                                        |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                                                                                      |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                  | 3     | 0,48 | The gypsum cardboard panels are fastened by screws. The connections between the steel elements are unclear and could be welded, as a separate adaptation is not reasonably expected, these connections are not considered.                                                                                                                                                         |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                                                              | 2.55 - 3.8 kN/m2 | 2     | 0,33 | The floor has a height of 242 mm, with a wooden plate screed. There are openings in the webs at certain locations through which the building services can be distributed over the floor surface area. The floor has a fixed height that can be used for spans of up to 7.2 m. As this is a span commonly used in residential buildings, a normal load-bearing capacity is assumed. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | A single type of connection is assumed for the connection of the floor elements.                                                                                                                                                                                                                                                                                                   |
|                            |        |                                                                                                                                                               |                  |       | 2,87 |                                                                                                                                                                                                                                                                                                                                                                                    |



## I.15 Topfloor

Table I.15: Flexibility assessment Topfloor

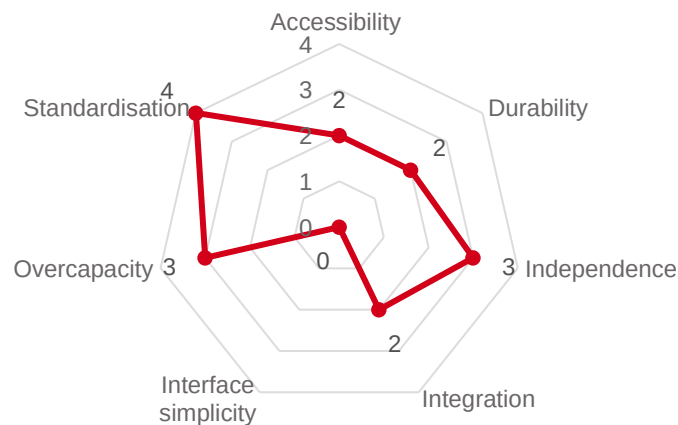
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                    |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through damaging operation, not affecting functionality                                                                                            |                  | 1     | 0,19 | Accessible through the screed, which is a reinforced steel slab                                                                                                             |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                  | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                      |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                  | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection. |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                  |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                                                      |                  | 0     | 0,00 | The different parts of the floor are cast into place, the cement bond is a hard chemical connection                                                                         |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                                                              | 2.55 - 3.8 kN/m2 | 2     | 0,33 | There is no information available on the height, span or load-bearing capacity. Normal values are assumed.                                                                  |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                  | 4     | 0,52 | A single type of connection is assumed for the connection of the floor elements.                                                                                            |
|                            |        |                                                                                                                                                               |                  |       | 1,90 |                                                                                                                                                                             |



## I.16 WestendDuo floor

Table I.16: Flexibility assessment WestendDuo floor

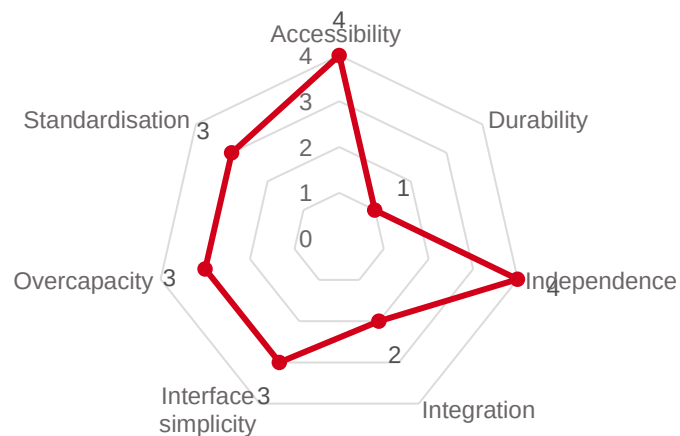
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                 | Score |      | Comments                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible through operation resulting in reparable damage                                                                                                    |                 | 2     | 0,37 | Accessible through a concrete screed                                                                                                                                                                                                                                                                                                                     |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a modest level of maintenance                                                                                     |                 | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                                                                   |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         |                 | 3     | 0,44 | The building services have their own space within the floor. The steel beams contain web openings through which piping can be laid, this is an intentional interconnection.                                                                                                                                                                              |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                 | 2     | 0,19 | The concrete and steel components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                                               |
| Interface simplicity       | 0,160  | Hard chemical connection                                                                                                                                      |                 | 0     | 0,00 | The different parts of the floor are cast into place, the cement bond is a hard chemical connection                                                                                                                                                                                                                                                      |
| Overcapacity               | 0,167  | 10 - 30% surplus                                                                                                                                              | 3.8 - 6.2 kN/m2 | 3     | 0,50 | There is no information available on the (surplus) height of the hollow space, a normal overcapacity is assumed for the building services. A high load-bearing overcapacity is assumed as the floor has a fixed floor height and can reach a span of up to 12 m, likely resulting in overcapacity for spans more commonly used in residential buildings. |
| Standardisation            | 0,13   | Only 1 type of detail and sizing used                                                                                                                         |                 | 4     | 0,52 | All interfaces are connected through cement bonding.                                                                                                                                                                                                                                                                                                     |
|                            |        |                                                                                                                                                               |                 |       | 2,26 |                                                                                                                                                                                                                                                                                                                                                          |



## I.17 Raised floor

Table I.17: Flexibility assessment raised floor

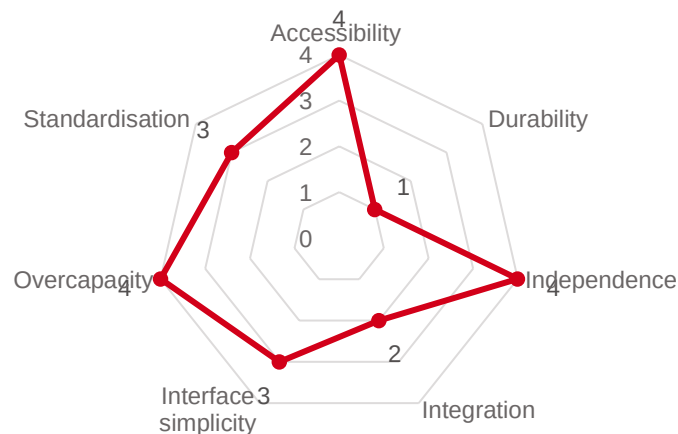
| Flexibility characteristic | Weight | Input                                                                                                                                                         |                  | Score |      | Comments                                                                                                                                                                                                                                            |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible without any operation                                                                                                                              |                  | 4     | 0,74 | Panels can be lifted for accessibility                                                                                                                                                                                                              |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a medium to high level of maintenance                                                                             |                  | 1     | 0,12 | Based on (Dias, 2003).                                                                                                                                                                                                                              |
| Independence               | 0,146  | Full separation of functions, no interconnections                                                                                                             |                  | 4     | 0,58 | The building services have their own space outside of the load-bearing floor                                                                                                                                                                        |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |                  | 2     | 0,19 | The load-bearing components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |                  | 3     | 0,48 | The pedestal jacks are connected through fasteners on top of the load-bearing floor                                                                                                                                                                 |
| Overcapacity               | 0,167  | ≥ 50% surplus                                                                                                                                                 | 2.55 - 3.8 kN/m2 | 3     | 0,50 | The building services can be freely placed underneath the raised floor, the height of the raised floor can be chosen based on the required space. The load-bearing capacity depends on the panels chosen, a normal load-bearing capacity is assumed |
| Standardisation            | 0,13   | 2 types of details and/or sizing used                                                                                                                         |                  | 3     | 0,39 | Different types of connections between the separate systems of the load-bearing floor and the raised floor                                                                                                                                          |
|                            |        |                                                                                                                                                               |                  |       | 3,00 |                                                                                                                                                                                                                                                     |



## I.18 Suspended ceiling

Table I.18: Flexibility assessment suspended ceiling

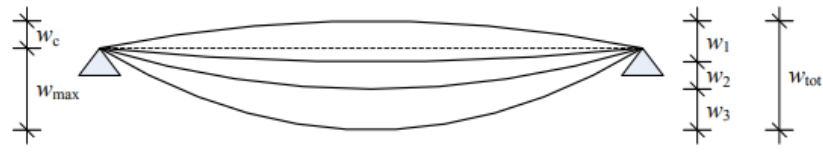
| Flexibility characteristic | Weight | Input                                                                                                                                                         |             | Score |      | Comments                                                                                                                                                                                                                                                                                                             |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible without any operation                                                                                                                              |             | 4     | 0,74 | Panels can be lifted for accessibility                                                                                                                                                                                                                                                                               |
| Durability                 | 0,119  | Minimum design life (≥ 50 years), requiring a medium to high level of maintenance                                                                             |             | 1     | 0,12 | Based on (Dias, 2003).                                                                                                                                                                                                                                                                                               |
| Independence               | 0,146  | Full separation of functions, no interconnections                                                                                                             |             | 4     | 0,58 | The building services have their own space outside of the load-bearing floor                                                                                                                                                                                                                                         |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system |             | 2     | 0,19 | The load-bearing components are integrated into a single technical element and are not reasonably expected to be adapted separately.                                                                                                                                                                                 |
| Interface simplicity       | 0,160  | Connections with added element                                                                                                                                |             | 3     | 0,48 | The system is suspended from the load-bearing structure above using connections with added elements, like hooks.                                                                                                                                                                                                     |
| Overcapacity               | 0,167  | ≥ 50% surplus                                                                                                                                                 | ≥ 6.2 kN/m2 | 4     | 0,67 | The building services can be freely placed above the suspended ceiling, the height of the suspended can be chosen based on required space. The load-bearing capacity is not relevant, as the ceiling panels do not need to bear imposed loads. Therefore a maximum score is given for the load-bearing overcapacity. |
| Standardisation            | 0,13   | 2 types of details and/or sizing used                                                                                                                         |             | 3     | 0,39 | Different types of connections between the separate systems of the load-bearing floor and the raised floor                                                                                                                                                                                                           |
|                            |        |                                                                                                                                                               |             |       | 3,17 |                                                                                                                                                                                                                                                                                                                      |





## Appendix J Building code requirements

Table J.1: Building code requirements

| Structural requirements                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dutch Building Decree ( <i>Bouwbesluit 2012, 2021</i> ) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Art. 2.3.1                                              | A roof or floor does not fail during the design lifetime indicated in NEN-EN 1990 under the combinations of actions for accidental design situations as defined in NEN-EN 1990. Here the impact action is assumed as indicated in NEN-EN 1991.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Art 2.4.1                                               | Not failing as indicated in articles 2.2 and 2.3 is determined according to: <ul style="list-style-type: none"> <li>- NEN-EN 1999 or NEN-EN 1993, in case of an aluminium or steel structure</li> <li>- NEN-EN 1992 or NEN-EN 1996, in case of a concrete or masonry structure</li> <li>- NEN-EN 1994, in case of a composite steel and concrete structure</li> <li>- NEN-EN 1995, in case of a timber structure</li> <li>- NEN-EN 2608, in case of a glass structure</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| NEN-EN 1990 (Nederlands Normalisatie-instituut, 2019c)  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 2.3                                                     | Building structures below to the design working life category 4 with an indicative design working life of 50 years.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| 6.4.3.3                                                 | <p><b>Combinations of actions for accidental design situations</b></p> <p>(1) The general format of effects of actions should be:</p> $E_d = E\{G_{k,j}; P; A_d; (\psi_{1,1} \text{ of } \psi_{2,1})Q_{k,1}; \psi_{2,i}Q_{k,i}\} \quad j \geq 1; i > 1 \quad (6.11a)$ <p>(2) The combination of actions in brackets <math>\{ \}</math> can be expressed as:</p> $\sum_{j \geq 1} G_{k,j} + P + A_d + (\psi_{1,1} \text{ of } \psi_{2,1})Q_{k,1} + \sum_{i > 1} \psi_{2,i}Q_{k,i} \quad (6.11b)$ <p>(3) The choice between <math>\psi_{1,1}Q_{k,1}</math> or <math>\psi_{2,1}Q_{k,1}</math> should be related to the relevant accidental design situation (impact, fire, or survival after an accidental event or situation)</p> <p>NOTE Guidance is given in the relevant parts of EN 1991 to EN 1999</p> <p>(4) Combinations of actions for accidental design situations should either</p> <ul style="list-style-type: none"> <li>- involve an explicit accidental action A (fire or impact), or</li> <li>- refer to a situation after an accidental event (<math>A=0</math>)</li> </ul> |
| A.1.4.2                                                 | <p>(1) Serviceability limit states in buildings should take into account criteria related, for example, to floor stiffness, differential floor levels, storey sway and/or building sway and roof stiffness. Stiffness criteria may be expressed in terms of limits for vertical deflection and vibration. Sway criteria may be expressed in terms of limits for horizontal displacements.</p> <p><u>National Annex:</u></p>  <p>It can be assumed that the aforementioned has been fulfilled if:</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | <ul style="list-style-type: none"> <li>- for floors carrying crack-sensitive walls, the sum of <math>w_2</math> and <math>w_3</math> for the frequent combination of actions (expression 6.15b), should be no bigger than <math>1/500</math> of <math>l_{rep}</math></li> <li>- for other floors and roofs that are used extensively by people, the sum of <math>w_2</math> and <math>w_3</math> for the frequent combination of actions (expression 6.15b), should be no bigger than <math>3/1000</math> of <math>l_{rep}</math>.</li> </ul> <p>Here <math>l_{rep}</math> is the span or twice the length of a cantilever</p> <p>The total horizontal displacement of buildings with more than one building layer for a characteristic action combination (expression 6.14.b) cannot be bigger than:</p> <ul style="list-style-type: none"> <li>- <math>h/300</math> per building layer</li> <li>- <math>h/500</math> for the entire building</li> </ul> <p>Here <math>h</math> is the smallest façade height of the smallest building layer height.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| A1.4.4                                                            | <p>(2) For the serviceability limit state of a structure or a structural member not to be exceeded when subject to vibration, the natural frequency of vibration of the structure or structural members should be kept above appropriate values which depend upon the function of the building and the source of vibration, and agreed with the client and/or the relevant authority.</p> <p><u>National Annex</u><br/>Resonance as a result of moving persons should be counteracted.</p> <p>In a pretensioned structure, the pretension load as part of the permanent load should be disregarded in the assessment of resonance.</p> <p>Remark 1: Usually, for floors that are frequently walked upon, such as floors of residential buildings or offices, the serviceability limit state will not be exceeded if the first eigenfrequency of the floor is not lower than 3 Hz (the highest frequency that can be induced by people with walking is 3 Hz). This is also the case if the sum of all characteristic values of the permanent and <math>\psi_2</math> times the variable load is at least <math>5 \text{ kN/m}^2</math>, or in case of a floor supported by beams, a total of 150 kN per beam (in case a load of <math>5 \text{ kN/m}^2</math> or 150 kN is present, it can be assumed that the floor can be made to vibrate noticeable through walking persons. In many cases, a maximum deflection for short term behaviour for a quasi-permanent combination (expression 6.16n) of 33 mm suffices. Especially for light floors, the preceding can be insufficient to prevent complaints. For specific criteria and determination procedures for floor beams or light floors, the SBR-guideline "Trillingen van vloeren door lopen" can be followed.</p> |
| <b>NEN-EN 1991-1-1 (Nederlands Normalisatie-instituut, 2019d)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 6.2.1                                                             | <p>(1)P For the design of a floor structure within one storey or a roof, the imposed load shall be taken into account as a free action applied at the most unfavourable part of the influence area of the action effects considered.</p> <p>(2) Where the loads on other storeys are relevant, they may be assumed to be distributed uniformly (fixed actions).</p> <p>(3)P To ensure a minimum local resistance of the floor structure a separate verification shall be performed with a concentrated load that, unless stated otherwise, shall not be combined with the uniformly distributed loads or other variable actions.</p> <p>(4) Imposed loads from a single category may be reduced according to the areas supported by the appropriate number, by a reduction factor <math>\alpha_A</math> according to 6.3.1.2(10).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 6.3.1.1                                                           | <p>(1)P Areas in residential, social, commercial and administration buildings shall be divided into categories according to their specific uses shown in Table 6.1</p> <p><b>Category A:</b> Areas for domestic and residential buildings</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

|                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6.3.1.2                                                          | <p>(1)P The categories of loaded areas, as specified in Table 6.1, shall be designed by using characteristic values <math>q_k</math> (uniformly distributed load) and <math>Q_k</math> (concentrated load)</p> <p>Table 6.2: <b>Category A: non communal floors, stairways and balconies</b><br/> <math>q_k = 1,75 \text{ kN/m}^2</math><br/> <math>Q_k = 3 \text{ kN}</math></p> <p>(3) For local verification a concentrated load <math>Q_k</math> acting alone should be taken into account.</p> <p>(5)P The concentrated load shall be considered to act at any point on the floor, balcony or stairs over an area with a shape that is appropriate to the use and form of the floor.</p> <p>(8) Provided that a floor allows for a lateral distribution of loads, the self-weight of movable partitions may be taken into account by a uniformly distributed load <math>q_k</math> which should be added to the imposed loads of floors obtained from Table 6.2. This defined uniformly distributed load is dependent on the self-weight of the partitions as follows:</p> <ul style="list-style-type: none"> <li>- for movable partitions with a self-weight <math>\leq 1.0 \text{ kN/m}</math> wall length: <math>q_k = 0.5 \text{ kN/m}^2</math></li> <li>- for movable partitions with a self-weight <math>\leq 2.0 \text{ kN/m}</math> wall length: <math>q_k = 0.8 \text{ kN/m}^2</math></li> <li>- for movable partitions with a self-weight <math>\leq 3.0 \text{ kN/m}</math> wall length: <math>q_k = 1.2 \text{ kN/m}^2</math></li> </ul> |
| <b>NEN-EN 1991-1-7</b> (Nederlands Normalisatie-instituut, 2016) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 4.3.1                                                            | <p>(1) Design values for actions due to impact on the supporting structures (e.g. columns and walls of bridges or buildings) adjacent to various types of roads should be defined.</p> <p>The indicative equivalent static design forces due to vehicular impact on members supporting structures over or adjacent to roadways can be found in table NB.1 - 4.1 of the Dutch National Annex.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Fire safety requirements</b>                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Dutch Building Decree</b> ( <i>Bouwbesluit 2012, 2021</i> )   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Fire resistance</b>                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Art 2.10.1                                                       | A floor, a stairway or a ramp over which or under which an escape route is located, does not fail within 30 minutes in case of a fire in a sub-fire-compartment in which the escape route is not located. This is not applicable for floors of an outside space of a housing function.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Art 2.10.2                                                       | <p>A building structure does not fail in case of a fire in a fire-compartment in which the building structure is not located within the in table 2.10.1 [values given below] indicated time for a failure of a building structure within or adjacent to the fire compartment. Insofar as the building structure is a housing function, this does not apply for buildings structures in a sub-fire-compartment adjacent to this fire-compartment or an adjacent outside space.</p> <ul style="list-style-type: none"> <li>- Floors at <math>\leq 7 \text{ m}</math>: 60 min. fire resistance</li> <li>- Floors at <math>7 \text{ m} - 13 \text{ m}</math>: 90 min. fire resistance</li> <li>- Floors at <math>&gt; 13 \text{ m}</math>: 120 min. fire resistance</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Art. 2.10.3                                                      | In departure of article 2.10.2, the timeframe indicated in table 2.10.1 is reduced by 30 minutes, if no floor with a residential function is situated above 7 m and has a permanent fire load determined in accordance with NEN 6090 that does not exceed $500 \text{ MJ/m}^2$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Art. 2.11.1                                                      | In the determination of the failure of a building structure, as referenced in article 2.10, it is assumed that the accidental load combination according to NEN-EN 1990 can occur during a fire.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

|                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Art 2.11.2                                                   | <p>The time span of failure as referenced in article 2.10 is determined depending on the material of the building structure based on:</p> <ul style="list-style-type: none"> <li>- NEN-EN 1992, in case of a concrete structure</li> <li>- NEN-EN 1993, in case of a steel structure</li> <li>- NEN-EN 1994, in case of a composite steel and concrete structure</li> <li>- NEN-EN 1995, in case of a timber structure</li> <li>- NEN-EN 1996, in case of a masonry structure</li> <li>- NEN-EN 1999, in case of an aluminium structure</li> <li>- NEN-EN 6069, for the testing and classification of resistance to fire of building products and building elements</li> </ul> |
| <b>Development of fire and smoke</b>                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Art. 2.69.1                                                  | <p>For the upper side of a floor, stairway, or ramp, adjacent to inside, the air smoke class <math>s_{1f}</math> is applicable as well as the fire class given in table 2.66 [value given below], both determined according to NEN-EN 13501-1.</p> <ul style="list-style-type: none"> <li>- Fire class <math>C_f</math> for extra protected escape routes</li> <li>- Fire class <math>D_f</math> for protected escape routes and other</li> </ul>                                                                                                                                                                                                                              |
| Art 2.70.1                                                   | <p>For up to 5% of the total surface area of structural elements of each individual space, for which according to articles 2.67 up until including 2.69a a requirement applies, the requirement does not apply.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Restricting the spread of fire</b>                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Art 2.84.1                                                   | <p>The resistance to outbreak and propagation of fire determined in accordance with NEN 6068 of one fire-compartment to a different fire-compartment, to a closed space through which an extra protected escape route goes, to a non-closed-off escape route, and to an elevator shaft of a fire department elevator is at least 60 minutes.</p>                                                                                                                                                                                                                                                                                                                               |
| Art 2.84.2                                                   | <p>In departure from article 2.84.1, a resistance of 30 minutes is sufficient between a fire compartment and a closed space through which an extra protected escape route goes.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Art 2.84.3                                                   | <p>In departure from article 2.84.1, a resistance of 30 minutes is sufficient if:</p> <ol style="list-style-type: none"> <li>a) the permanent fire load, determined in accordance to NEN 6090, does not exceed 500 MJ/m<sup>2</sup>, and</li> <li>b) the building does not contain floors with a residential function above 7 m above ground.</li> </ol>                                                                                                                                                                                                                                                                                                                       |
| Art 2.84.7                                                   | <p>The articles 2.84.2 up until including 2.84.4 do not apply to spaces through which a safe escape route goes.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Acoustics</b>                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Dutch Building Decree (<i>Bouwbesluit 2012, 2021</i>)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Art 3.17a.1                                                  | <p>The characteristic air sound level difference, determined in accordance with NEN 5077, for the sound transmission between residential rooms within the same housing function is not smaller than 32 dB.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Art 3.17a.2                                                  | <p>The weighted contact sound level, determined in accordance with NEN 5077, for the sound transmission between residential rooms within the same housing function is not larger than 79 dB.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Art 3.17a.3                                                  | <p>Articles 3.17a.1 and 3.17a.2 do not apply if the residential areas are openly connected to each other, or if one residential area can be accessed from the other through a doorway.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

## Appendix K Structural calculations

### K.1 Option A.i: Long span with accessibility from the bottom

#### K.1.1 Input

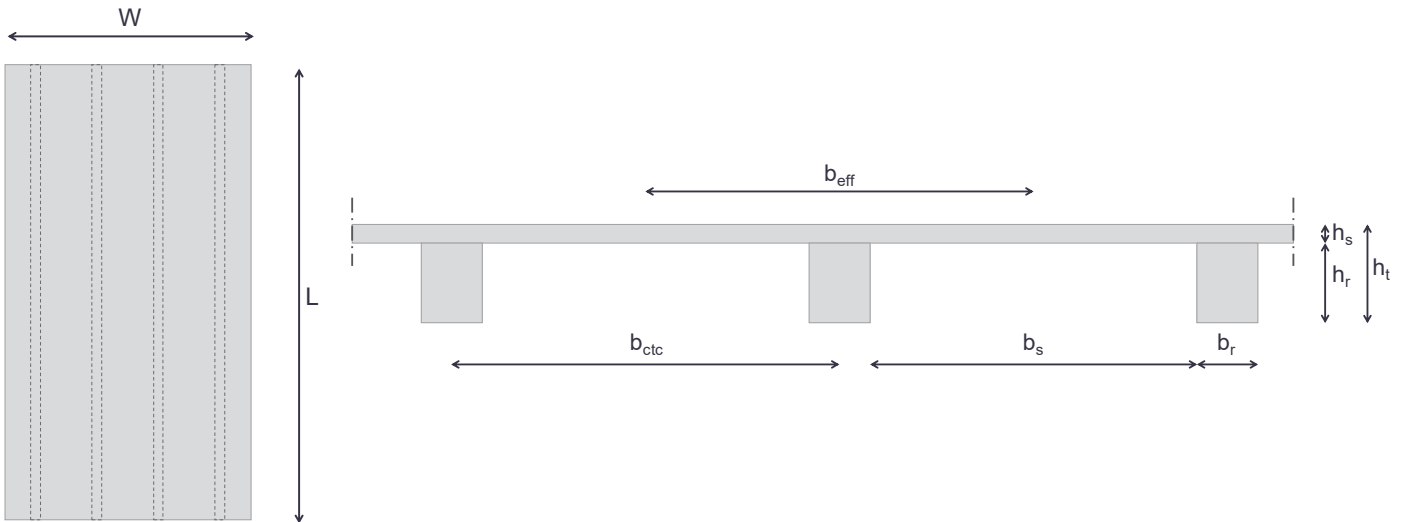


Figure K.1: Indication of the dimensions

| Dimensions                             |              |      |                   |                                                              |
|----------------------------------------|--------------|------|-------------------|--------------------------------------------------------------|
| Span                                   | L            | 6100 | mm                |                                                              |
| Width                                  | W            | 3300 | mm                |                                                              |
| Number of ribs                         | n            | 4    |                   |                                                              |
| Height slab                            | $h_s$        | 38   | mm                | $\geq \max[\varphi_{t,t}; \varphi_{t,b}] + 2 * c_{nom} = 38$ |
| Height rib                             | $h_r$        | 170  | mm                | $\geq 170$ mm                                                |
| Total height                           | $h_t$        | 208  | mm                | $h_t = h_s + h_r$                                            |
| Width rib                              | $b_r$        | 100  | mm                |                                                              |
| Space between ribs                     | $b_s$        | 725  | mm                | $\geq 170$ mm                                                |
| Centre to centre distance between ribs | $b_{ctc}$    | 825  | mm                | $b_{ctc} = b_r + b_s$                                        |
| Concrete properties                    |              |      |                   |                                                              |
| C30/37                                 |              |      |                   |                                                              |
| Density                                | $\rho_{rep}$ | 25   | kN/m <sup>3</sup> |                                                              |
| Characteristic cylinder strength       | $f_{ck}$     | 30   | N/mm <sup>2</sup> |                                                              |
| Partial safety factor concrete         | $\gamma_c$   | 1,5  |                   |                                                              |
| Design compressive strength            | $f_{cd}$     | 20   | N/mm <sup>2</sup> |                                                              |
| Design tensile strength                | $f_{ctd}$    | 1,35 | N/mm <sup>2</sup> |                                                              |
| Mean tensile strength                  | $f_{ctm}$    | 2,9  | N/mm <sup>2</sup> |                                                              |

| Reinforcement                                      |                  |      |                   |                                                         |
|----------------------------------------------------|------------------|------|-------------------|---------------------------------------------------------|
| Longitudinal reinforcement                         |                  |      |                   |                                                         |
| Diameter longitudinal reinforcement                | $\varphi_l$      | 12   | mm                |                                                         |
| Number of longitudinal reinforcement bars          | n                | 4    |                   |                                                         |
| Surface area longitudinal reinforcement            | $A_{sl}$         | 452  | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$              |
| Spacing of longitudinal reinforcement              | $s_l$            | 25   | mm                | $s_l = \frac{b_r}{n}$                                   |
| Effective height of the cross-section              | d                | 185  | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$         |
|                                                    |                  |      |                   |                                                         |
| Transversal reinforcement top                      |                  |      |                   |                                                         |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars top       | n                | 9    |                   |                                                         |
| Surface area transversal reinforcement bars top    | $A_{st,t}$       | 113  | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$        |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$        | 111  | mm                | $s_{t,t} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | d                | 19   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
|                                                    |                  |      |                   |                                                         |
| Transversal reinforcement bottom                   |                  |      |                   |                                                         |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars bottom    | n                | 9    |                   |                                                         |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$       | 113  | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$        |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$        | 111  | mm                | $s_{t,b} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | d                | 19   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
|                                                    |                  |      |                   |                                                         |
| Concrete cover                                     |                  |      |                   |                                                         |
| Minimum cover due to environmental conditions      | $c_{min,dur}$    | 10   | mm                | XC1                                                     |
| Minimum cover due to bond requirement              | $c_{min,b}$      | 12   | mm                | EN 1992-1-1                                             |
| Minimum cover                                      | $c_{min}$        | 12   | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10\text{mm}\}$ |
| Allowance in design for deviation                  | $\Delta c_{dev}$ | 5    | mm                | EN 1992-1-1/NB                                          |
| Nominal cover                                      | $c_{nom}$        | 17   | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$                    |
|                                                    |                  |      |                   |                                                         |
| Reinforcement steel                                |                  |      |                   |                                                         |
| B500 B                                             |                  |      |                   |                                                         |
| Yield strength                                     | $f_{yk}$         | 500  | N/mm <sup>2</sup> |                                                         |
| Partial safety factor steel                        | $\gamma_s$       | 1,15 |                   |                                                         |
| Design yield stress                                | $f_{yd}$         | 435  | N/mm <sup>2</sup> |                                                         |



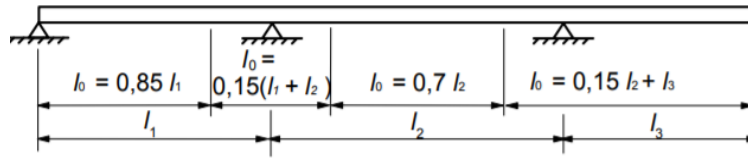


Figure K.2: Definition of  $l_0$ , for calculation of effective flange width from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

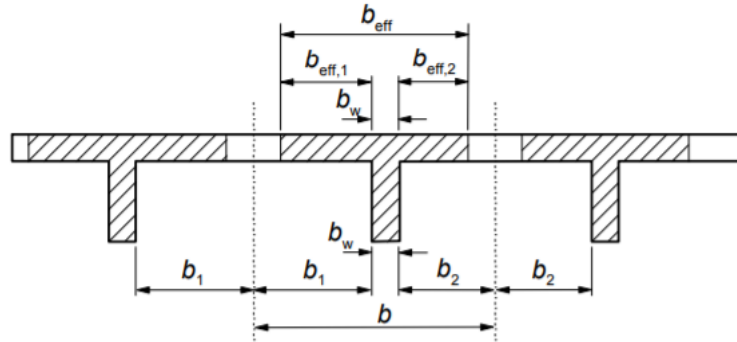


Figure K.3: Effective flange width parameters from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |       |    |                                           |
|------------------------|-------|----|-------------------------------------------|
| $l_1$                  | 6100  | mm | $l_1 = L$                                 |
| $l_0$                  | 5185  | mm | $l_0 = 0,85l_1$                           |
| $b_1$                  | 362,5 | mm | $b_1 = 0.5 * b_s$                         |
| $b_2$                  | 362,5 | mm | $b_2 = 0.5 * b_s$                         |
| $b_w$                  | 100   | mm | $b_w = b_r$                               |
| $b$                    | 825   | mm | $b = b_{ctc}$                             |
| $b_{eff,1}$            | 591   | mm | $b_{eff,1} = 0.2b_1 + 0.1l_0 \leq 0.2l_0$ |
| $b_{eff,2}$            | 591   | mm | $b_{eff,2} = 0.2b_2 + 0.1l_0 \leq 0.2l_0$ |
| $b_{eff}$              | 825   |    | $b_{eff} = \sum b_{eff,i} + b_w \leq b$   |

### K.1.2 Loads

| Permanent loads                       |                |      |                   |                                                                                                   |
|---------------------------------------|----------------|------|-------------------|---------------------------------------------------------------------------------------------------|
| Slab                                  | $g_{slab}$     | 0,95 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                                                     |
| Rib                                   | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                                      |
| Top floor panels                      | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                                                   |
| Building services                     | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                                              |
| Total deadload longitudinal direction | $g_{k,l}$      | 1,62 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                       |
| Total deadload transversal direction  | $g_{k,t}$      | 1,97 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1\ m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1\ m]$ |

|                                                     |              |      |                   |                                    |
|-----------------------------------------------------|--------------|------|-------------------|------------------------------------|
|                                                     |              |      |                   |                                    |
| <b>Variable load</b>                                |              |      |                   |                                    |
| Variable floor load residential buildings           | $q_{res}$    | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                     |
| Movable partitions                                  | $q_{part}$   | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                        |
|                                                     |              |      |                   |                                    |
| Total variable floor load in longitudinal direction | $q_{k,l}$    | 2,10 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$      |
| Total variable floor load in transversal direction  | $q_{k,t}$    | 2,55 | kN/m              | $q_{k,t} = q_{tot} * [1\text{ m}]$ |
|                                                     |              |      |                   |                                    |
| <b>Load combination ULS</b>                         |              |      |                   |                                    |
| Partial factor for permanent loads                  | $\gamma_G$   | 1,35 |                   | EN 1990/NB                         |
| Partial factor for variable loads                   | $\gamma_Q$   | 1,5  |                   | EN 1990/NB                         |
|                                                     |              |      |                   |                                    |
| ULS load combination in longitudinal direction      | $q_{ULS,l}$  | 5,34 | kN/m              | EN 1990 6.10a                      |
| ULS load combination in transversal direction       | $q_{ULS,t}$  | 6,48 | kN/m              | EN 1990 6.10a                      |
|                                                     |              |      |                   |                                    |
| <b>Load combination SLS</b>                         |              |      |                   |                                    |
| Factor for frequent value of a variable action      | $\psi_{1,1}$ | 0,5  |                   | EN 1990                            |
|                                                     |              |      |                   |                                    |
| SLS load combination in longitudinal direction      | $q_{SLS,l}$  | 2,67 | kN/m              | EN 1990 6.15a                      |
| SLS load combination in transversal direction       | $q_{SLS,t}$  | 3,24 | kN/m              | EN 1990 6.15a                      |

### K.1.3 Ultimate limit state – Longitudinal direction

#### Load distribution

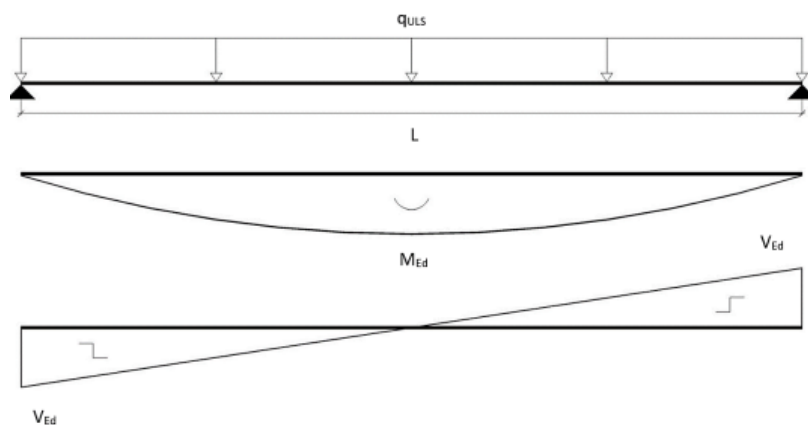


Figure K.4: Load distribution in the longitudinal direction

|                               |          |       |     |                                      |
|-------------------------------|----------|-------|-----|--------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 24,86 | kNm | $M_{Ed} = \frac{1}{8} q_{ULS,l} l^2$ |
| Maximum acting shear force    | $V_{Ed}$ | 16,30 | kN  | $V_{Ed} = \frac{1}{2} q_{ULS,l} l$   |
|                               |          |       |     |                                      |

#### Bending moment reinforcement

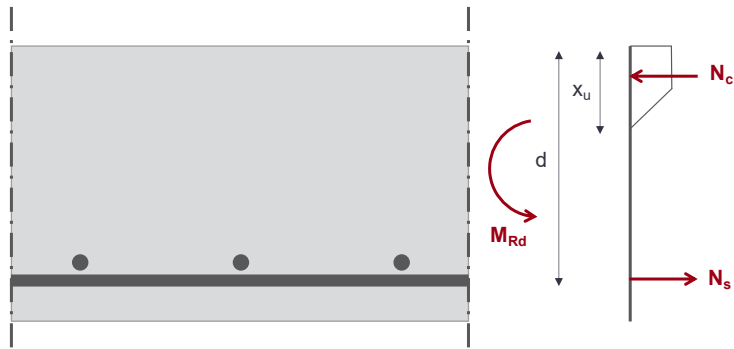


Figure K.5: Concrete cross-section

|                                                         |            |          |                   |                                                                              |
|---------------------------------------------------------|------------|----------|-------------------|------------------------------------------------------------------------------|
| Rebar tensile force                                     | $N_s$      | 196691   | N                 | $N_s = A_{sl} * f_{yd}$                                                      |
| Concrete compressive force                              | $N_c$      |          | N                 | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                 |
| Concrete compressive zone height                        | $x_u$      | 15,89    | mm                | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$ |
|                                                         |            |          |                   |                                                                              |
| Bending moment resistance                               | $M_{Rd}$   | 35168600 | Nmm               | $M_{Rd} = N_s * (d - 0.39x_u)$                                               |
|                                                         |            | 35,17    | kNm               |                                                                              |
|                                                         |            |          |                   |                                                                              |
| Unity Check                                             | 0,71       | ≤        | 1,0               |                                                                              |
|                                                         |            |          |                   |                                                                              |
| <b>Shear reinforcement</b>                              |            |          |                   |                                                                              |
| <b>Minimal reinforcement</b>                            |            |          |                   |                                                                              |
|                                                         | k          | 2,0      |                   | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                      |
| Smallest width of the cross-section in the tensile area | $b_w$      | 100      | mm                |                                                                              |
| Reinforcement ratio for longitudinal reinforcement      | $\rho_l$   | 0,0245   |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                    |
|                                                         | $C_{Rd,c}$ | 0,12     |                   | EN 1992-1-1/NB                                                               |
|                                                         | $v_{min}$  | 0,30     | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                   |
|                                                         |            |          |                   |                                                                              |
| Shear force resistance                                  | $V_{Rd,c}$ | 18587    | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w * d$  |
|                                                         |            | 19       | kN                | $\leq v_{min} * b_w * d$                                                     |
|                                                         |            |          |                   |                                                                              |
| Unity Check                                             | 0,88       | ≤        | 1,0               | No shear reinforcement required                                              |

### K.1.4 Ultimate limit state – Transversal direction

#### Load distribution

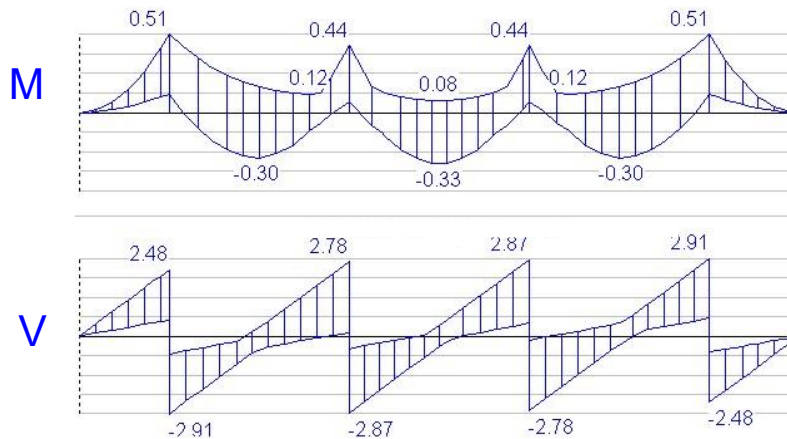


Figure K.6: Load distribution in transversal direction (enveloping fundamental combination using Technosoft Liggers)

|                                      |                 |      |     |  |
|--------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment top    | $M_{Ed,top}$    | 0,51 | kNm |  |
| Maximum acting bending moment bottom | $M_{Ed,bottom}$ | 0,33 | kNm |  |
| Maximum acting shear force           | $V_{Ed}$        | 2,91 | kN  |  |
|                                      |                 |      |     |  |

#### Bending moment reinforcement

##### Bending moment reinforcement at the top

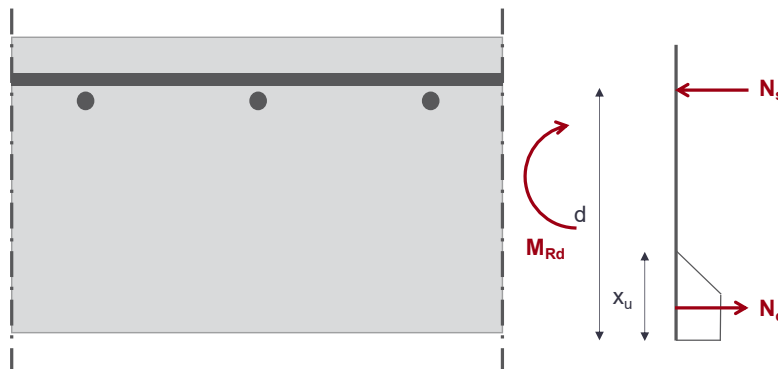


Figure K.7: Concrete cross-section top reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 49173  | N   | $N_s = A_{st,t} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,28   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
|                                  |          |        |     |                                                                                   |
| Bending moment resistance        | $M_{Rd}$ | 871415 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,87   | kNm |                                                                                   |
|                                  |          |        |     |                                                                                   |
| Unity Check                      | 0,38     | ≤      | 1,0 |                                                                                   |
|                                  |          |        |     |                                                                                   |

##### Bending moment reinforcement at the bottom

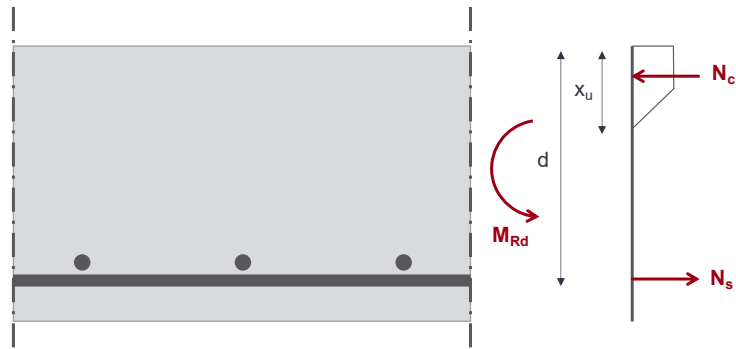


Figure K.8: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 49173  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,28   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 871415 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,87   | kNm |                                                                                   |
| Unity Check                      | 0,59     | ≤      | 1,0 |                                                                                   |

#### Shear in web-flange interface

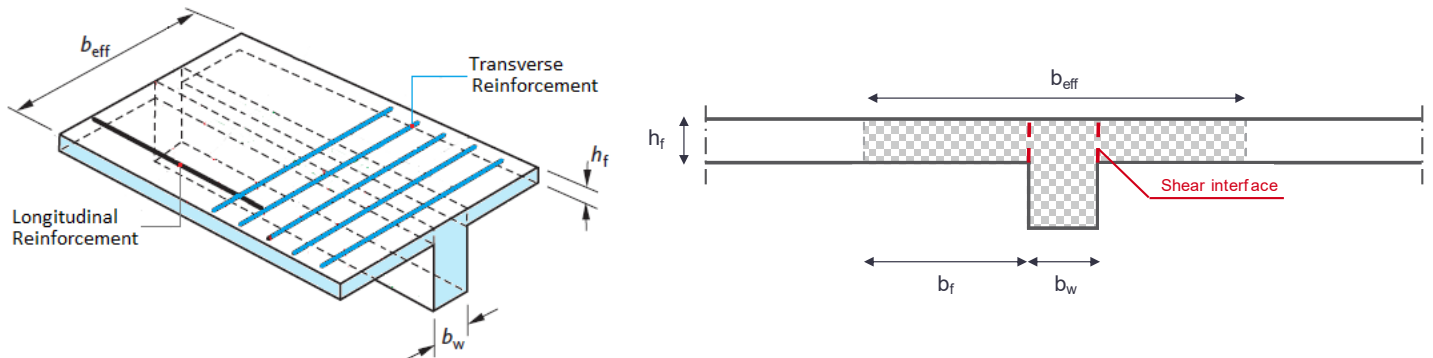


Figure K.9: Parameters for shear in the web-flange interface (Walraven, 2011)

|                 |          |       |                   |                                                                   |
|-----------------|----------|-------|-------------------|-------------------------------------------------------------------|
| Width of flange | $b_f$    | 362,5 | mm                |                                                                   |
| Shear stress    | $v_{Ed}$ | 0,20  | N/mm <sup>2</sup> | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$        |
|                 | k        | 0,4   |                   | EN 1992-1-1/NB                                                    |
| Check           | 0,20     | ≤     | 0,54              | $v_{ed} \leq k * f_{ctd}$<br>No transverse reinforcement required |

### K.1.5 Serviceability limit state

| Reinforcement for crack control                                                                                          |                |       |                   |                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------|----------------|-------|-------------------|--------------------------------------------------------------------------------------|
| Minimum areas of reinforcement                                                                                           |                |       |                   |                                                                                      |
| Absolute value of the maximum stress permitted in the reinforcement immediately after the formation of the crack         | $\sigma_s$     | 500   | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which takes account of the stress distribution within the section immediately prior to cracking              | $k_c$          | 0,4   |                   | EN 1992-1-1                                                                          |
| Mean value of the tensile strength of the concrete effective at the times when the cracks may first be expected to occur | $f_{ct,eff}$   | 2,9   | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which allows for the effect of non-uniform self-equilibrating                                                |                |       |                   |                                                                                      |
| Slab                                                                                                                     | $k$            | 0,65  |                   | EN 1992-1-1                                                                          |
| Rib                                                                                                                      | $k$            | 1,00  |                   | EN 1992-1-1                                                                          |
| Area of concrete within the tensile zone                                                                                 |                |       |                   |                                                                                      |
| Rib (longitudinal direction)                                                                                             | $A_{ct,r}$     | 8500  | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the top (transversal direction)                                                               | $A_{ct,t,t}$   | 19000 | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the bottom (transversal direction)                                                            | $A_{ct,t,b}$   | 19000 | mm <sup>2</sup>   |                                                                                      |
| Minimum area of reinforcement                                                                                            |                |       |                   |                                                                                      |
| Rib (longitudinal direction)                                                                                             | $A_{smin,l,r}$ | 20    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab with reinforcement at the top (transversal direction)                                                               | $A_{smin,t,t}$ | 29    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab with reinforcement at the bottom (transversal direction)                                                            | $A_{smin,t,b}$ | 29    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| The minimum areas of reinforcement are included in the reinforcement requirements in Appendix K.1.6                      |                |       |                   |                                                                                      |
| Restrictions for bar diameters and spacing                                                                               |                |       |                   |                                                                                      |
| Limit value crack width                                                                                                  | $w_{max}$      | 0,4   | mm                | EN 1992-1-1/NB                                                                       |
| Longitudinal direction                                                                                                   |                |       |                   |                                                                                      |
| Bending moment in SLS                                                                                                    | $M_{Efreq}$    | 12,43 | kNm               | $M_{Ed} = \frac{1}{8} q_{SLS,l} l^2$                                                 |
| Bending moment resistance                                                                                                | $M_{Rd}$       | 35,17 | kNm               |                                                                                      |
| Steel stress                                                                                                             | $\sigma_s$     | 154   | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
| Maximum bar size                                                                                                         | $\varphi'_s$   | 41    | mm                | EN 1992-1-1                                                                          |
| Adapted maximum bar size                                                                                                 | $\varphi_s$    | 36    | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2,9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
| Check $\varphi_s > \varphi_l$                                                                                            | 36             | mm    | >                 | 12 mm                                                                                |
| Transversal direction                                                                                                    |                |       |                   |                                                                                      |



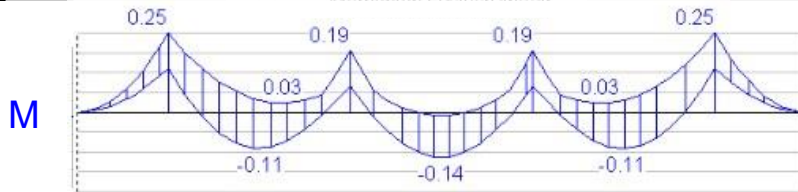


Figure K.10: Load distribution in transversal direction (frequent combination using Technosoft Liggers)

|                                           |              |          |                   |                                                                                                                                                                                          |
|-------------------------------------------|--------------|----------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bending moment SLS, top                   | $M_{Efreq}$  | 0,25     | kNm               |                                                                                                                                                                                          |
| Bending moment SLS, bottom                | $M_{Efreq}$  | 0,14     | kNm               |                                                                                                                                                                                          |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Bending moment resistance, top            | $M_{Rd}$     | 0,86     | kNm               |                                                                                                                                                                                          |
| Bending moment resistance, bottom         | $M_{Rd}$     | 0,86     | kNm               |                                                                                                                                                                                          |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Steel stress, top                         | $\sigma_s$   | 125      | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                           |
| Steel stress, bottom                      | $\sigma_s$   | 70       | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                           |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Maximum bar size, top                     | $\varphi'_s$ | 47       | mm                | EN 1992-1-1                                                                                                                                                                              |
| Maximum bar size, bottom                  | $\varphi'_s$ | 59       | mm                | EN 1992-1-1                                                                                                                                                                              |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Adapted maximum bar size, top             | $\varphi_s$  | 9        | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                                     |
| Adapted maximum bar size, bottom          | $\varphi_s$  | 12       | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                                     |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Check $\varphi_s > \varphi_{t,t}$         | 9            | mm       | >                 | 4 mm                                                                                                                                                                                     |
| Check $\varphi_s > \varphi_{t,b}$         | 12           | mm       | >                 | 4 mm                                                                                                                                                                                     |
|                                           |              |          |                   |                                                                                                                                                                                          |
| <b>Slenderness for deflection control</b> |              |          |                   |                                                                                                                                                                                          |
| <b>Longitudinal direction</b>             |              |          |                   |                                                                                                                                                                                          |
| Reference reinforcement ratio             | $\rho_0$     | 0,005477 |                   | $\rho_0 = 10^{-3} * \sqrt{f_{ck}}$                                                                                                                                                       |
| Tension reinforcement ratio               | $\rho_l$     | 0,009357 |                   | $\rho_l = \frac{A_{sl}}{A}$                                                                                                                                                              |
| Factor for different structural systems   | K            | 1        |                   | EN 1992-1-1                                                                                                                                                                              |
| Compression reinforcement ratio           | $\rho'_l$    | 0        |                   |                                                                                                                                                                                          |
|                                           |              |          |                   |                                                                                                                                                                                          |
| Limit span/depth                          | $l/d$        | 16       |                   | $\frac{l}{d}$<br>$= K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_l - \rho'_l} \right]$<br>$+ \frac{1}{12} \sqrt{f_{ck}} \sqrt{\frac{\rho'_l}{\rho_0}} \text{ if } \rho_l > \rho_0$ |
| Corrective value for slenderness          |              | 2,02     |                   | $\frac{310}{\sigma_s}$                                                                                                                                                                   |
| Adapted span/depth limit                  |              | 32       |                   |                                                                                                                                                                                          |
|                                           |              |          |                   |                                                                                                                                                                                          |

|                                          |              |          |   |                                                                                                                                                                                 |
|------------------------------------------|--------------|----------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Check                                    | l/h          | 29       | < | 32                                                                                                                                                                              |
| <b>Transversal direction</b>             |              |          |   |                                                                                                                                                                                 |
| Tension reinforcement ratio, top         | $\rho_{t,t}$ | 0,002976 |   | $\rho_{t,t} = \frac{A_{st,t}}{A}$                                                                                                                                               |
| Tension reinforcement ratio, bottom      | $\rho_{t,b}$ | 0,002976 |   | $\rho_{t,b} = \frac{A_{st,b}}{A}$                                                                                                                                               |
| Factor for different structural systems  | K            | 1,5      |   | EN 1992-1-1                                                                                                                                                                     |
| Compression reinforcement ratio          | $\rho'_i$    | 0        |   |                                                                                                                                                                                 |
| Limit span/depth, top                    | l/d          | 59       |   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
| Limit span/depth, bottom                 | l/d          | 59       |   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
| Corrective value for slenderness, top    |              | 2,49     |   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Corrective value for slenderness, bottom |              | 4,44     |   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Adapted span/depth limit, top            |              | 148      |   |                                                                                                                                                                                 |
| Adapted span/depth limit, bottom         |              | 264      |   |                                                                                                                                                                                 |
| Check, top                               | l/h          | 22       | < | 148                                                                                                                                                                             |
| Check, bottom                            | l/h          | 22       | < | 264                                                                                                                                                                             |

### K.1.6 Detailing reinforcement requirements

| Minimum longitudinal tension reinforcement area |               |         |                 |                                                      |
|-------------------------------------------------|---------------|---------|-----------------|------------------------------------------------------|
| Section Modulus                                 | W             | 1075462 | mm <sup>3</sup> |                                                      |
| Minimum principal reinforcement area (1)        | $A_{s,min,1}$ | 1194359 | mm <sup>2</sup> | $A_{s,min,1} = \frac{f_{ctm} * W}{f_{yd} * 0.9 * d}$ |
| Required reinforcement area for ULS             | $A_s$         | 343     | mm <sup>2</sup> | $A_s = \frac{M_{Ed}}{f_{yd} * 0.9 * d}$              |
| Minimum principal reinforcement area (2)        | $A_{s,min,2}$ | 429     | mm <sup>2</sup> | $A_{s,min,2} = 1.25 A_s$                             |
| Minimum principal reinforcement area            | $A_{s,min}$   | 429     | mm <sup>2</sup> | $A_{s,min} = \min[A_{s,min,1}; A_{s,min,2}]$         |
| Maximum reinforcement area                      |               |         |                 |                                                      |
| Longitudinal direction                          |               |         |                 |                                                      |

|                                                                     |                     |                 |                 |                                                       |
|---------------------------------------------------------------------|---------------------|-----------------|-----------------|-------------------------------------------------------|
| Cross-sectional area of concrete                                    | $A_c$               | 48350           | mm <sup>2</sup> | $A_c = b_{eff} * h_s + b_r * h_r$                     |
| Maximum reinforcement area                                          | $A_{s,max}$         | 1934            | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                              |
| <b>Transversal direction</b>                                        |                     |                 |                 |                                                       |
| Cross-sectional area of concrete                                    | $A_c$               | 38000           | mm <sup>2</sup> | $A_c = h_s * [1 m]$                                   |
| Maximum reinforcement area                                          | $A_{s,max}$         | 1520            | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                              |
| <b>Minimum reinforcement spacing</b>                                |                     |                 |                 |                                                       |
|                                                                     | $k_1$               | 1               |                 | EN 1992-1-1/NB                                        |
| Minimum reinforcement spacing (1) longitudinal reinforcement        | $s_{min,1,l}$       | 12              | mm              | $s_{min,1} = k_1 * \varphi_l$                         |
| Minimum reinforcement spacing (1) transversal reinforcement, top    | $s_{min,1,t,t}$     | 4               | mm              | $s_{min,1} = k_1 * \varphi_{t,t}$                     |
| Minimum reinforcement spacing (1) transversal reinforcement, bottom | $s_{min,1,t,b}$     | 4               | mm              | $s_{min,1} = k_1 * \varphi_{t,b}$                     |
| Maximum size of aggregate                                           | $d_g$               | 16              | mm              | Assumption                                            |
|                                                                     | $k_2$               | 5               |                 | EN 1992-1-1/NB                                        |
| Minimum reinforcement spacing (2)                                   | $s_{min,2}$         | 21              | mm              | $s_{min,2} = d_g + k_2$                               |
| Minimum reinforcement spacing longitudinal reinforcement            | $s_{min,l}$         | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |
| Minimum reinforcement spacing transversal reinforcement, top        | $s_{min,t,t}$       | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |
| Minimum reinforcement spacing transversal reinforcement, bottom     | $s_{min,t,b}$       | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |
| <b>Maximum reinforcement spacing</b>                                |                     |                 |                 |                                                       |
| Maximum reinforcement spacing for principal reinforcement           | $s_{max,principal}$ | 250             | mm              | $s_{max,principal} = 2 * h_t \leq 250 \text{ mm}$     |
| Maximum reinforcement spacing for secondary reinforcement           | $s_{max,secondary}$ | 114             | mm              | $s_{max,secondary} = 3 * h_s \leq 400 \text{ mm}$     |
| <b>Check</b>                                                        |                     |                 |                 |                                                       |
| <b>Longitudinal reinforcement</b>                                   |                     |                 |                 |                                                       |
| Area of rebar                                                       | 429                 | mm <sup>2</sup> | <               | 452 mm <sup>2</sup> < 1934 mm <sup>2</sup>            |
| Spacing of rebar                                                    | 21                  | mm              | <               | 25 mm < 250 mm                                        |
| <b>Transversal reinforcement</b>                                    |                     |                 |                 |                                                       |
| Area of rebar top                                                   | 29                  | mm <sup>2</sup> | <               | 113 mm <sup>2</sup> < 1520 mm <sup>2</sup>            |
| Spacing of rebar top                                                | 21                  | mm              | <               | 111 mm < 114 mm                                       |
| Area of rebar bottom                                                | 29                  | mm <sup>2</sup> | <               | 113 mm <sup>2</sup> < 1520 mm <sup>2</sup>            |
| Spacing of rebar bottom                                             | 21                  | mm              | <               | 111 mm < 114 mm                                       |

### K.1.7 Rib openings

| Input       |       |    |    |  |
|-------------|-------|----|----|--|
| Height slab | $h_s$ | 38 | mm |  |

|                                           |             |       |                 |                                                 |
|-------------------------------------------|-------------|-------|-----------------|-------------------------------------------------|
| Height rib at opening                     | $h_r$       | 22,5  | mm              | $h_{r,o} = \frac{h_r - 125}{2}$                 |
| Total height                              | $h_t$       | 60,5  | mm              | $h_t = h_s + h_{r,o}$                           |
| Nominal cover                             | $c_{nom}$   | 17    | mm              |                                                 |
| Diameter longitudinal reinforcement       | $\varphi_l$ | 12    | mm              |                                                 |
| Number of longitudinal reinforcement bars | $n$         | 4     |                 |                                                 |
| Surface area longitudinal reinforcement   | $A_{sl}$    | 452   | mm <sup>2</sup> | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$      |
| Spacing of longitudinal reinforcement     | $s_l$       | 25    | mm              | $s_l = \frac{b_r}{n}$                           |
| Diameter stirrups                         | $\varphi_s$ | 6     | mm              |                                                 |
| Surface area stirrups                     | $A_{sw}$    | 28,27 | mm <sup>2</sup> | $A_{sw} = n * \frac{1}{4} \pi \varphi_s^2$      |
| Effective height of the cross-section     | $d_l$       | 31,5  | mm              | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$ |

### Load distribution

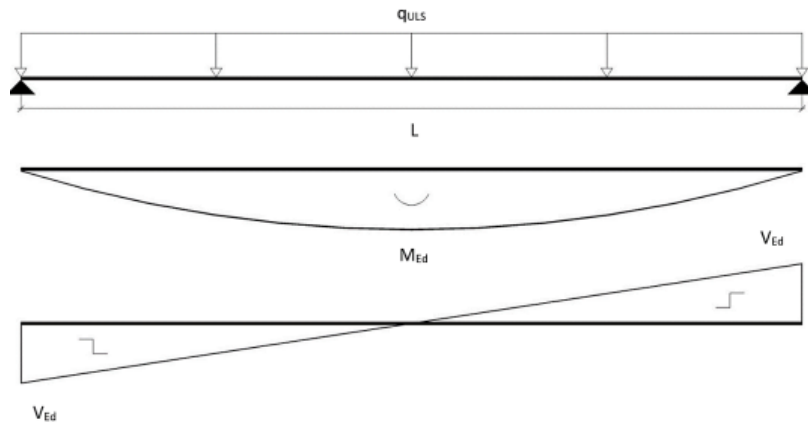


Figure K.11: Load distribution in the longitudinal direction

|                                             |            |       |     |                                             |
|---------------------------------------------|------------|-------|-----|---------------------------------------------|
| Maximum allowable bending moment at opening | $M_{Ed,o}$ | 4,97  | kNm | See unity check longitudinal bending moment |
| Maximum acting shear force                  | $V_{Ed}$   | 16,30 | kN  | $V_{Ed} = \frac{1}{2} q l$                  |

### Bending moment reinforcement

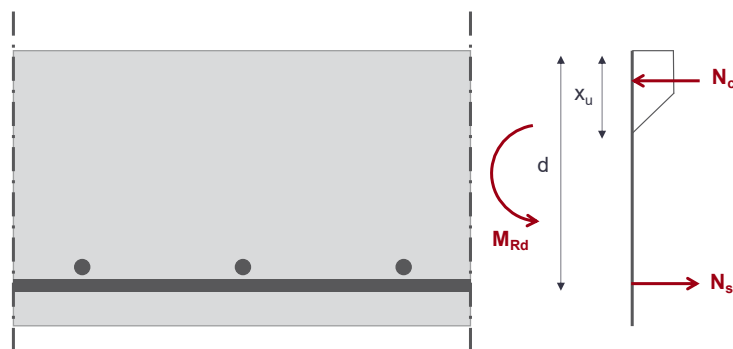


Figure K.12: Concrete cross-section

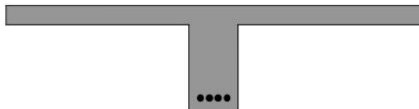
|                     |       |        |   |                         |
|---------------------|-------|--------|---|-------------------------|
| Rebar tensile force | $N_s$ | 196691 | N | $N_s = A_{sl} * f_{yd}$ |
|---------------------|-------|--------|---|-------------------------|

|                                                                                  |               |         |                   |                                                                                                         |
|----------------------------------------------------------------------------------|---------------|---------|-------------------|---------------------------------------------------------------------------------------------------------|
| Concrete compressive force                                                       | $N_c$         |         | N                 | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                                            |
| Concrete compressive zone height                                                 | $x_u$         | 15,89   | mm                | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$                            |
|                                                                                  |               |         |                   |                                                                                                         |
| Bending moment resistance                                                        | $M_{Rd}$      | 4976529 | Nmm               | $M_{Rd} = N_s * (d - 0.39x_u)$                                                                          |
|                                                                                  |               | 4,98    | kNm               |                                                                                                         |
|                                                                                  |               |         |                   |                                                                                                         |
| Unity Check                                                                      | 1,00          | ≤       | 1                 |                                                                                                         |
| Distance from the end of the beam where the opening can be located               | $x$           | 0,32    | m                 | $\frac{qlx}{2} - \frac{qx^2}{2} - M_{Ed} = 0$                                                           |
|                                                                                  |               |         |                   |                                                                                                         |
| <b>Shear reinforcement</b>                                                       |               |         |                   |                                                                                                         |
| <b>Minimal reinforcement</b>                                                     |               |         |                   |                                                                                                         |
|                                                                                  | $k$           | 2,0     |                   | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                                 |
| Smallest width of the cross-section in the tensile area                          | $b_w$         | 100     | mm                |                                                                                                         |
| Reinforcement ratio for longitudinal reinforcement                               | $\rho_l$      | 0,144   |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                               |
|                                                                                  | $C_{Rd,c}$    | 0,12    |                   | EN 1992-1-1/NB                                                                                          |
|                                                                                  | $v_{min}$     | 0,30    | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                              |
|                                                                                  |               |         |                   |                                                                                                         |
|                                                                                  | $V_{Rd,c}$    | 5710    | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w * d$<br>$\leq v_{min} * b_w * d$ |
|                                                                                  |               | 6       | kN                |                                                                                                         |
|                                                                                  |               |         |                   |                                                                                                         |
| Unity Check                                                                      | 2,85          | ≤       | 1,0               | Shear reinforcement required at the openings                                                            |
|                                                                                  |               |         |                   |                                                                                                         |
| <b>Maximum resistance</b>                                                        |               |         |                   |                                                                                                         |
| Coefficient taking into account the state of the stress in the compression chord | $\alpha_{cw}$ | 1       |                   | EN 1992-1-1/NB                                                                                          |
| strength reduction factor for concrete cracked in shear                          | $v_1$         | 0,6     |                   | EN 1992-1-1/NB                                                                                          |
| Angle of the inclined struts                                                     | $\theta$      | 45      | °                 | Assumption                                                                                              |
|                                                                                  |               |         |                   |                                                                                                         |
| Limit value for shear resistance                                                 | $V_{Rd,max}$  | 17010   | N                 | $V_{Rd,max} = \alpha_{cw} * b_w * z * v_1 * f_{cd} / (\cot(\theta) + \tan(\theta))$                     |
|                                                                                  |               | 17      | kN                |                                                                                                         |
|                                                                                  |               |         |                   |                                                                                                         |
| Unity Check                                                                      | 0,96          | ≤       | 1                 | The cross-section is able to take the shear forces                                                      |
|                                                                                  |               |         |                   |                                                                                                         |
| <b>Required shear reinforcement</b>                                              |               |         |                   |                                                                                                         |

|                     |              |       |                     |                                                                 |
|---------------------|--------------|-------|---------------------|-----------------------------------------------------------------|
|                     | $A_{sw}/s_w$ | 1,32  | mm <sup>2</sup> /mm | $\frac{A_{sw}}{s_w} = \frac{V_{Ed} * \tan(\theta)}{z * f_{yd}}$ |
| Spacing of stirrups | $s_w$        | 21,38 | mm                  |                                                                 |

### K.1.8 Check of manual calculations

The previous calculations are manual calculations done using Microsoft Excel. To ensure the accuracy of these calculations, a number of the manually calculated values are checked using Technosoft Construct. The results of the manual calculations and the Technosoft output are in the same order of magnitude and therefore correspond sufficiently.

| Bending moment resistance – Longitudinal direction                                  |                                           |                 |               |  |
|-------------------------------------------------------------------------------------|-------------------------------------------|-----------------|---------------|--|
| Manual calculation                                                                  | M <sub>Rd</sub>                           | 35,17           | kNm           |  |
| Technosoft output                                                                   | M <sub>Rd</sub>                           | 37,2            | kNm           |  |
| Toegepaste normen volgens Eurocode met Nederlandse NB                               |                                           |                 |               |  |
| Belastingen                                                                         | NEN-EN 1990:2002                          | C2:2010         | NB:2011 (nl)  |  |
|                                                                                     | NEN-EN 1991-1-1:2002                      | C1:2009         | NB:2011 (nl)  |  |
| Beton                                                                               | NEN-EN 1992-1-1:2011 (nl)                 | C2/A1:2015 (nl) | NB:2016 (nl)  |  |
| Controle hoofdwapening. (B)                                                         |                                           |                 |               |  |
| GEOMETRIE                                                                           |                                           |                 |               |  |
| Elementtype                                                                         | : Balk                                    |                 |               |  |
| Betonkwaliteit                                                                      | : C30/37                                  |                 |               |  |
| Soort spanningsrekdiagram                                                           | : Parabolisch - rechthoekig diagram       |                 |               |  |
| Doorsnede vorm                                                                      | : T1                                      |                 |               |  |
| Afmetingen                                                                          | : b=825 h=208 b1=363 h1=170 b2=363 h2=170 |                 |               |  |
| Scheurvorming volgens art                                                           | : 7.3.4                                   |                 |               |  |
| Referentieperiode                                                                   | : 50 jaar                                 |                 |               |  |
|  |                                           |                 |               |  |
| WAPENING                                                                            |                                           |                 |               |  |
| Staalkwaliteit                                                                      | : B500B                                   |                 |               |  |
| Soort spanningsrekdiagram                                                           | : Bi-lineair diagram met klimmende tak    |                 |               |  |
| Beugeldiameter                                                                      | : 0                                       |                 |               |  |
| Toevallige inklemming                                                               | : nee                                     |                 |               |  |
| Toegepaste wapening                                                                 | :                                         | Boven<br>0x12   | Onder<br>4x12 |  |
| Breedte stort sleuf                                                                 | :                                         | 50              |               |  |
| Betondekking                                                                        |                                           |                 |               |  |
| Milieu                                                                              | :                                         | Boven<br>XC1    | Onder<br>XC1  |  |
| Gestort tegen bestaand beton                                                        | :                                         | Nee             | Nee           |  |
| Element met plaatgeometrie                                                          | :                                         | Nee             | Nee           |  |
| Specifieke kwaliteitsbeheersing                                                     | :                                         | Nee             | Nee           |  |
| Oneffen beton oppervlak                                                             | :                                         | Nee             | Nee           |  |
| Ondergrond                                                                          | :                                         | Glad / N.v.t.   | Glad / N.v.t. |  |
| Constructieklasse                                                                   | :                                         | S3              | S3            |  |
| Grootste korrel                                                                     | :                                         | 16.0            |               |  |
| Hoofdwapening                                                                       | :                                         | 1ste laag       | 1ste laag     |  |
| Nominale dekking                                                                    | :                                         | 17              | 17            |  |
| Toegepaste dekking                                                                  | :                                         | 17              | 17            |  |
| Gelijkwaardige diameter                                                             | :                                         | 12              | 12            |  |
| C <sub>min,b</sub> C <sub>min,dur</sub> ΔC <sub>dur</sub>                           | :                                         | 12 10 0         | 12 10 0       |  |
| C <sub>min</sub> ΔC <sub>dev</sub> C <sub>nom</sub>                                 | :                                         | 12 5 17         | 12 5 17       |  |



| BELASTING |                  |                   | RESULTATEN           |                       |                   |                   |                       |                       |  |
|-----------|------------------|-------------------|----------------------|-----------------------|-------------------|-------------------|-----------------------|-----------------------|--|
| Nr        | Sterkte          |                   | Scheurvorming        |                       | Opm.              |                   |                       |                       |  |
|           | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] |  |
| 1         | 0.0              | -24.9             | 0.0                  | 0.0                   | 0.5               | -37.2             | 0.0                   | -40.8                 |  |

Figure K.13: Output Technosoft Construct Bending reinforcement in the longitudinal direction

### Bending moment resistance – Transversal direction

|                           |            |      |     |
|---------------------------|------------|------|-----|
| Manual calculation top    | $M_{Rd,t}$ | 0,87 | kNm |
| Manual calculation bottom | $M_{Rd,b}$ | 0,87 | kNm |
| Technosoft output top     | $M_{Rd,t}$ | 0,9  | kNm |
| Technosoft output bottom  | $M_{Rd,b}$ | 0,9  | kNm |

### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                           |                 |              |
|-------------|---------------------------|-----------------|--------------|
| Belastingen | NEN-EN 1990:2002          | C2:2010         | NB:2011(nl)  |
|             | NEN-EN 1991-1-1:2002      | C1:2009         | NB:2011(nl)  |
| Beton       | NEN-EN 1992-1-1:2011 (nl) | C2/A1:2015 (nl) | NB:2016 (nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=38                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevallige inklemming     | : nee                                  |
| Toegepaste wapening       | : Boven 9x4                            |
| Breedte stort sleuf       | : 50                                   |
|                           | : Onder 0x4                            |

#### Betondekking

|                                            |                 |               |
|--------------------------------------------|-----------------|---------------|
| Milieu                                     | : Boven XC1     | Onder XC1     |
| Gestort tegen bestaand beton               | : Nee           | Nee           |
| Element met plaatgeometrie                 | : Nee           | Nee           |
| Specifieke kwaliteitsbeheersing            | : Nee           | Nee           |
| Oneffen beton oppervlak                    | : Nee           | Nee           |
| Ondergrond                                 | : Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                          | : S3            | S3            |
| Grootste korrel                            | : 16.0          |               |
| Hoofdwapening                              | : 1ste laag     | 1ste laag     |
| Nominale dekking                           | : 15            | 15            |
| Toegepaste dekking                         | : 17            | 17            |
| Gelijkwaardige diameter                    | : 4             | 4             |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 4 10 0        | 4 10 0        |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 10 5 15       | 10 5 15       |

| BELASTING |                         |                          |                             |                              | RESULTATEN               |                          |                              |                              |      |
|-----------|-------------------------|--------------------------|-----------------------------|------------------------------|--------------------------|--------------------------|------------------------------|------------------------------|------|
| Nr        | N <sub>Ed</sub><br>[kN] | M <sub>Ed</sub><br>[kNm] | N <sub>E,freq</sub><br>[kN] | M <sub>E,freq</sub><br>[kNm] | Sterkte                  |                          | Scheurvorming                |                              | Opm. |
|           |                         |                          |                             |                              | M <sub>Rd</sub><br>[kNm] | M <sub>Rd</sub><br>[kNm] | M <sub>R,freq</sub><br>[kNm] | M <sub>R,freq</sub><br>[kNm] |      |
| 1         | 0.0                     | -0.5                     | 0.0                         | 0.0                          | 0.9                      | -0.5                     | 0.0                          | -0.0                         | 11   |

Figure K.14: Output Technosoft Construct Bending reinforcement in transversal direction top

#### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

#### Controle hoofdwapening. (B)

##### GEOMETRIE

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=38                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |



##### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalige inklemming      | : nee                                  |

|                     |         |       |
|---------------------|---------|-------|
| Toegepaste wapening | : Boven | Onder |
| Breedte stortstleuf | : 0x12  | 9x4   |
|                     | : 50    |       |

|                                                           |                 |               |               |
|-----------------------------------------------------------|-----------------|---------------|---------------|
| <b>Betondekking</b>                                       |                 | Boven         | Onder         |
| Milieu                                                    | : XC1           | XC1           | XC1           |
| Gestort tegen bestaand beton                              | : Nee           | Nee           | Nee           |
| Element met plaatgeometrie                                | : Nee           | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing                           | : Nee           | Nee           | Nee           |
| Oneffen beton oppervlak                                   | : Nee           | Nee           | Nee           |
| Ondergrond                                                | : Glad / N.v.t. | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                                         | : S3            | S3            | S3            |
| Grootste korrel                                           | : 16.0          |               |               |
| Hoofdwapening                                             | : 1ste laag     | 1ste laag     |               |
| Nominale dekking                                          | : 17            | 15            |               |
| Toegepaste dekking                                        | : 17            | 17            |               |
| Gelijkwaardige diameter                                   | : 12            | 4             |               |
| C <sub>min,b</sub> C <sub>min,dur</sub> ΔC <sub>dur</sub> | : 12 10 0       | 4 10 0        |               |
| C <sub>min</sub> ΔC <sub>dev</sub> C <sub>nom</sub>       | : 12 5 17       | 10 5 15       |               |

| BELASTING |                         |                          |                             |                              | RESULTATEN               |                          |                              |                              |      |
|-----------|-------------------------|--------------------------|-----------------------------|------------------------------|--------------------------|--------------------------|------------------------------|------------------------------|------|
| Nr        | N <sub>Ed</sub><br>[kN] | M <sub>Ed</sub><br>[kNm] | N <sub>E,freq</sub><br>[kN] | M <sub>E,freq</sub><br>[kNm] | Sterkte                  |                          | Scheurvorming                |                              | Opm. |
|           |                         |                          |                             |                              | M <sub>Rd</sub><br>[kNm] | M <sub>Rd</sub><br>[kNm] | M <sub>R,freq</sub><br>[kNm] | M <sub>R,freq</sub><br>[kNm] |      |
| 1         | 0.0                     | -0.3                     | 0.0                         | 0.0                          | 0.5                      | -0.9                     | 0.0                          | -0.0                         | 167  |

Figure K.15: Output Technosoft Construct Bending reinforcement in transversal direction top

#### Shear force resistance – Longitudinal direction

|                    |                   |       |    |
|--------------------|-------------------|-------|----|
| Manual calculation | V <sub>Rd,c</sub> | 18,59 | kN |
|--------------------|-------------------|-------|----|

|                   |            |       |    |
|-------------------|------------|-------|----|
| Technosoft output | $V_{Rd,c}$ | 16,74 | kN |
|-------------------|------------|-------|----|

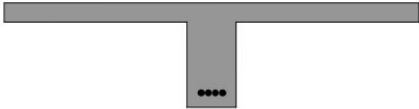
  

|                                                              |                          |                |             |
|--------------------------------------------------------------|--------------------------|----------------|-------------|
| <b>Toegepaste normen volgens Eurocode met Nederlandse NB</b> |                          |                |             |
| Belastingen                                                  | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|                                                              | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton                                                        | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

|                                     |                                           |  |  |
|-------------------------------------|-------------------------------------------|--|--|
| <b>Dwarskracht en wringing. (B)</b> |                                           |  |  |
| <b>GEOMETRIE</b>                    |                                           |  |  |
| Elementtype                         | : Balk                                    |  |  |
| Betonkwaliteit                      | : C30/37                                  |  |  |
| Soort spanningsrekdiagram           | : Parabolisch - rechthoekig diagram       |  |  |
| Doorsnede vorm                      | : T1                                      |  |  |
| Afmetingen                          | : b=825 h=208 b1=363 h1=170 b2=363 h2=170 |  |  |
| Referentieperiode                   | : 50 jaar                                 |  |  |



|                           |                                        |       |       |
|---------------------------|----------------------------------------|-------|-------|
| <b>WAPENING</b>           |                                        |       |       |
| Staalkwaliteit            | : B500B                                |       |       |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |       |       |
| Toevallige inklemming     | : nee                                  |       |       |
| Toegepaste wapening       |                                        | Boven | Onder |
| Breedte stort sleuf       |                                        | 0x12  | 4x12  |
|                           |                                        | 50    |       |

|                                            |   |               |               |
|--------------------------------------------|---|---------------|---------------|
| <b>Betondekking</b>                        |   |               |               |
| Milieu                                     | : | Boven<br>XC1  | Onder<br>XC1  |
| Gestort tegen bestaand beton               | : | Nee           | Nee           |
| Element met plaatgeometrie                 | : | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing            | : | Nee           | Nee           |
| Oneffen beton oppervlak                    | : | Nee           | Nee           |
| Ondergrond                                 | : | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                          | : | S3            | S3            |
| Grootste korrel                            | : | 16.0          |               |
| Hoofdwapening                              | : | 2de laag      | 2de laag      |
| Nominale dekking                           | : | 17            | 17            |
| Toegepaste dekking                         | : | 22            | 22            |
| Gelijkwaardige diameter                    | : | 12            | 12            |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : | 12 10 0       | 12 10 0       |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : | 12 5 17       | 12 5 17       |

|                                            |                        |           |                                   |
|--------------------------------------------|------------------------|-----------|-----------------------------------|
| Beugel / Verdeelwapening                   | :                      | 1ste laag | 1ste laag                         |
| Nominale dekking                           | :                      | 15        | 15                                |
| Toegepaste dekking                         | :                      | 17        | 17                                |
| Gelijkwaardige diameter                    | :                      | 5         | 5                                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | :                      | 5 10 0    | 5 10 0                            |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | :                      | 10 5 15   | 10 5 15                           |
| Minimale beugelafstand                     | :                      | 21        | Theta [graden] : 21.8             |
| Uitg.p. inw.hefboomsarm z                  | :                      | 0,9*d     |                                   |
| <b>BELASTING</b>                           |                        |           |                                   |
| NEd                                        | [kN] :                 | 0.0       | MEd [kNm] : 0.0                   |
| VEd                                        | [kN] :                 | 16.3      | TEd [kNm] : 0.0                   |
| Q-permanent                                | [kN/m] :               | 0.0       | Veiligheidsklasse : 1             |
| Q-veranderlijk                             | [kN/m] :               | 0.0       | Gamma-permanent : 1.08            |
| L                                          | [m] :                  | 6.1       | Gamma-veranderlijk : 1.35         |
|                                            |                        |           | X [m] : 0.0                       |
| <b>RESULTATEN</b>                          |                        |           |                                   |
| Beugeldiameter                             | [mm] :                 | 5         | z [mm] : 162.00                   |
| Trekzijde                                  | :                      | Onder     | Wapeningsverhouding : 0.00305     |
| Dwarskracht                                |                        |           | Wringing                          |
| $V_{Rd,max}$                               | [kN] :                 | 58.40     | $T_{Rd,max}$ [kNm] : 2.83         |
| $V_{Ed}$                                   | [kN] :                 | 16.30     | $T_{Ed}$ [kNm] : 0.00             |
| $V_{Rd,c}$                                 | [kN] :                 | 16.74     | $T_{RD,c}$ [kNm] : 1.05           |
| A-opg                                      | [mm <sup>2</sup> /m] : | 0.00      | A-langs [mm <sup>2</sup> ] : 0.00 |
| A-bgl                                      | [mm <sup>2</sup> /m] : | 0.00      | A-bgl [mm <sup>2</sup> /m] : 0.00 |
| H.o.h. afstand                             | [mm] :                 | 300.0     | Aant. beugelsneden/drsn: 1        |

Figure K.16: Output Technosoft Construct shear reinforcement in the longitudinal direction

## K.2 Option A.ii: Long span with accessibility from the top

### K.2.1 Input

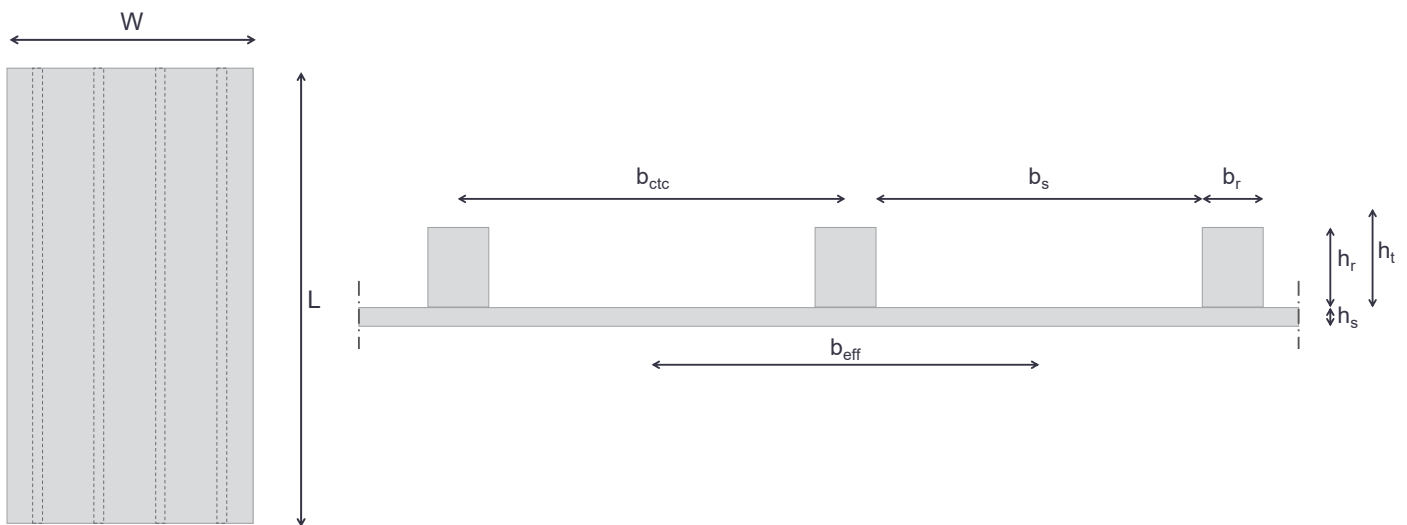


Figure K.17: Indication of the dimensions

| Dimensions     |       |      |    |                                                                         |
|----------------|-------|------|----|-------------------------------------------------------------------------|
| Span           | L     | 6100 | mm |                                                                         |
| Width          | W     | 3300 | mm |                                                                         |
| Number of ribs | n     | 3    |    |                                                                         |
| Height slab    | $h_s$ | 36   | mm | $\geq \max[\varphi_{t,t}; \varphi_{t,b}; \varphi_l] + 2 * c_{nom} = 36$ |
| Height rib     | $h_r$ | 170  | mm | $\geq 170$ mm                                                           |
| Total height   | $h_t$ | 206  | mm | $h_t = h_s + h_r$                                                       |

|                                                    |                 |      |                   |                                                  |
|----------------------------------------------------|-----------------|------|-------------------|--------------------------------------------------|
| Width rib                                          | $b_r$           | 326  | mm                |                                                  |
| Space between ribs                                 | $b_s$           | 774  | mm                | $\geq 170$ mm                                    |
| Centre to centre distance between ribs             | $b_{ctc}$       | 1100 | mm                | $b_{ctc} = b_r + b_s$                            |
| <b>Concrete properties</b>                         |                 |      |                   |                                                  |
| C30/37                                             |                 |      |                   |                                                  |
| Density                                            | $\rho_{rep}$    | 25   | kN/m <sup>3</sup> |                                                  |
| Characteristic cylinder strength                   | $f_{ck}$        | 30   | N/mm <sup>2</sup> |                                                  |
| Partial safety factor concrete                     | $\gamma_c$      | 1,5  |                   |                                                  |
| Design compressive strength                        | $f_{cd}$        | 20   | N/mm <sup>2</sup> |                                                  |
| Design tensile strength                            | $f_{ctd}$       | 1,35 | N/mm <sup>2</sup> |                                                  |
| Mean tensile strength                              | $f_{ctm}$       | 2,9  | N/mm <sup>2</sup> |                                                  |
| <b>Reinforcement properties</b>                    |                 |      |                   |                                                  |
| <b>Longitudinal reinforcement</b>                  |                 |      |                   |                                                  |
| Diameter longitudinal reinforcement                | $\varphi_l$     | 6    | mm                |                                                  |
| Number of longitudinal reinforcement bars          | $n$             | 24   |                   |                                                  |
| Surface area longitudinal reinforcement            | $A_{sl}$        | 679  | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$       |
| Spacing of longitudinal reinforcement              | $s_l$           | 45   | mm                | $s_l = \frac{b_{eff}}{n}$                        |
| Effective height of the cross-section              | $d_l$           | 188  | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$  |
| <b>Transversal reinforcement top</b>               |                 |      |                   |                                                  |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$ | 6    | mm                |                                                  |
| Number of transversal reinforcement bars top       | $n$             | 10   |                   |                                                  |
| Surface area transversal reinforcement bars top    | $A_{st,t}$      | 283  | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$ |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$       | 100  | mm                | $s_{t,t} = \frac{[1\text{ m}]}{n}$               |
| Effective height of the cross-section              | $d_l$           | 18   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$  |
| <b>Transversal reinforcement bottom</b>            |                 |      |                   |                                                  |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$ | 4    | mm                |                                                  |
| Number of transversal reinforcement bars bottom    | $n$             | 10   |                   |                                                  |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$      | 126  | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$ |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$       | 100  | mm                | $s_{t,b} = \frac{[1\text{ m}]}{n}$               |
| Effective height of the cross-section              | $d_l$           | 19   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$  |
| <b>Concrete cover</b>                              |                 |      |                   |                                                  |

|                                               |                  |      |                   |                                                         |
|-----------------------------------------------|------------------|------|-------------------|---------------------------------------------------------|
| Minimum cover due to environmental conditions | $c_{min,dur}$    | 10   | mm                | XC1                                                     |
| Minimum cover due to bond requirement         | $c_{min,b}$      | 6    | mm                | EN 1992-1-1                                             |
| Minimum cover                                 | $c_{min}$        | 10   | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10\text{mm}\}$ |
| Allowance in design for deviation             | $\Delta c_{dev}$ | 5    | mm                | EN 1992-1-1/NB                                          |
| Nominal cover                                 | $c_{nom}$        | 15   | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$                    |
| <b>Reinforcement steel</b>                    |                  |      |                   |                                                         |
| <b>B500 B</b>                                 |                  |      |                   |                                                         |
| Yield strength                                | $f_{yk}$         | 500  | N/mm <sup>2</sup> |                                                         |
| Partial safety factor steel                   | $\gamma_s$       | 1,15 |                   |                                                         |
| Design yield stress                           | $f_{yd}$         | 435  | N/mm <sup>2</sup> |                                                         |

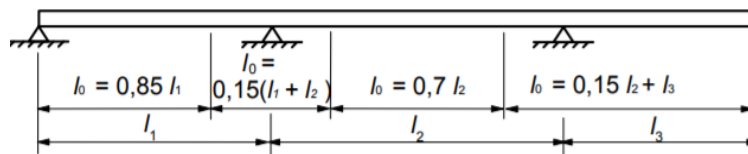


Figure K.18: Definition of  $l_0$ , for calculation of effective flange width from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

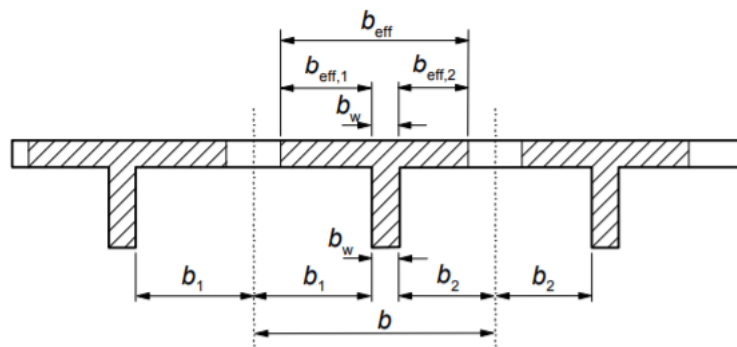


Figure K.19: Effective flange width parameters from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |      |    |                                              |
|------------------------|------|----|----------------------------------------------|
| $l_1$                  | 6100 | mm | $l_1 = L$                                    |
| $l_0$                  | 3050 | mm | $l_0 = 0,85 l_1$                             |
|                        |      |    |                                              |
| $b_1$                  | 387  | mm | $b_1 = 0,5 * b_s$                            |
| $b_2$                  | 387  | mm | $b_2 = 0,5 * b_s$                            |
| $b_w$                  | 326  | mm | $b_w = b_r$                                  |
| $b$                    | 1100 | mm | $b = b_{ctc}$                                |
|                        |      |    |                                              |
| $b_{eff,1}$            | 382  | mm | $b_{eff,1} = 0,2 b_1 + 0,1 l_0 \leq 0,2 l_0$ |
| $b_{eff,2}$            | 382  | mm | $b_{eff,2} = 0,2 b_2 + 0,1 l_0 \leq 0,2 l_0$ |
|                        |      |    |                                              |
| $b_{eff}$              | 1091 | mm | $b_{eff} = \sum b_{eff,i} + b_w \leq b$      |



## K.2.2 Loads

| Permanent loads                                     |                |      |                   |                                                                                                   |
|-----------------------------------------------------|----------------|------|-------------------|---------------------------------------------------------------------------------------------------|
| Slab                                                | $g_{slab}$     | 0,90 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                                                     |
| Rib                                                 | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                                      |
| Ceiling panels                                      | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                                                   |
| Building services                                   | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                                              |
|                                                     |                |      |                   |                                                                                                   |
| Total deadload longitudinal direction               | $g_{k,l}$      | 2,93 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                       |
| Total deadload transversal direction                | $g_{k,t}$      | 2,66 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1\ m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1\ m]$ |
|                                                     |                |      |                   |                                                                                                   |
| Variable load                                       |                |      |                   |                                                                                                   |
| Variable floor load residential buildings           | $q_{res}$      | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                                                    |
| Movable partitions                                  | $q_{part}$     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                                       |
|                                                     |                |      |                   |                                                                                                   |
| Total variable floor load in longitudinal direction | $q_{k,l}$      | 2,81 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                                                     |
| Total variable floor load in transversal direction  | $q_{k,t}$      | 2,55 | kN/m              | $q_{k,t} = q_{tot} * [1\ m]$                                                                      |
|                                                     |                |      |                   |                                                                                                   |
| Load combination ULS                                |                |      |                   |                                                                                                   |
| Partial factor for permanent loads                  | $\gamma_G$     | 1,35 |                   | EN 1990/NB                                                                                        |
| Partial factor for variable loads                   | $\gamma_Q$     | 1,5  |                   | EN 1990/NB                                                                                        |
|                                                     |                |      |                   |                                                                                                   |
| ULS load combination in longitudinal direction      | $q_{ULS,l}$    | 8,16 | kN/m              | EN 1990 6.10a                                                                                     |
| ULS load combination in transversal direction       | $q_{ULS,t}$    | 7,42 | kN/m              | EN 1990 6.10a                                                                                     |
|                                                     |                |      |                   |                                                                                                   |
| Load combination SLS                                |                |      |                   |                                                                                                   |
| Factor for frequent value of a variable action      | $\psi_{1,1}$   | 0,5  |                   | EN 1990                                                                                           |
|                                                     |                |      |                   |                                                                                                   |
| SLS load combination in longitudinal direction      | $q_{SLS,l}$    | 4,33 | kN/m              | EN 1990 6.15a                                                                                     |
| SLS load combination in transversal direction       | $q_{SLS,t}$    | 3,93 | kN/m              | EN 1990 6.15a                                                                                     |

### K.2.3 Ultimate limit state – Longitudinal direction

#### Load distribution

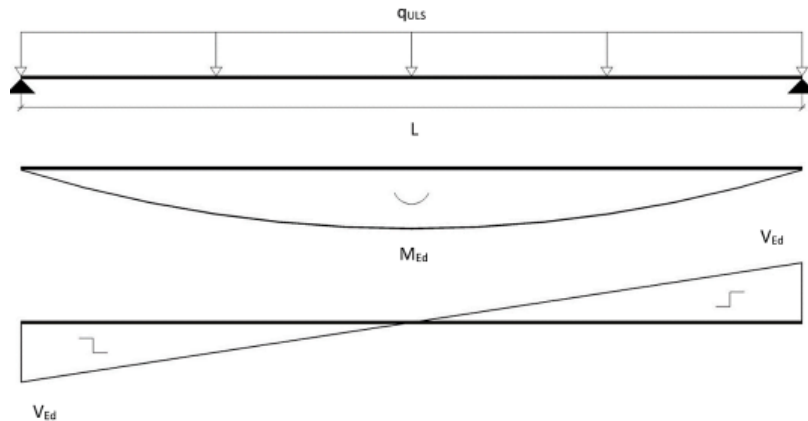


Figure K.20: Load distribution in the longitudinal direction

|                               |          |       |     |                                    |
|-------------------------------|----------|-------|-----|------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 37,94 | kNm | $M_{Ed} = \frac{1}{8} q_{ULT} l^2$ |
| Maximum acting shear force    | $V_{Ed}$ | 24,88 | kN  | $V_{Ed} = \frac{1}{2} q_{ULT} l$   |
|                               |          |       |     |                                    |

#### Bending moment reinforcement

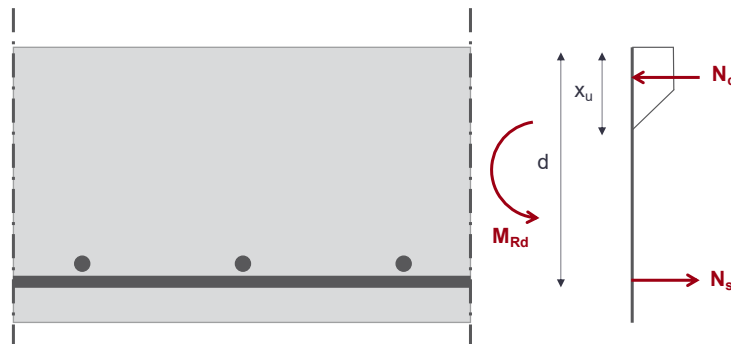


Figure K.21: Concrete cross-section

|                                  |          |          |     |                                                                              |
|----------------------------------|----------|----------|-----|------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 295037   | N   | $N_s = A_{sl} * f_{yd}$                                                      |
| Concrete compressive force       | $N_c$    |          | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                 |
| Concrete compressive zone height | $x_u$    | 60,33    | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$ |
|                                  |          |          |     |                                                                              |
| Bending moment resistance        | $M_{Rd}$ | 48524504 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                               |
|                                  |          | 48,52    | kNm |                                                                              |
|                                  |          |          |     |                                                                              |
| Unity Check                      | 0,78     | ≤        | 1,0 |                                                                              |
|                                  |          |          |     |                                                                              |

#### Shear reinforcement

##### Minimal reinforcement

|  |   |     |  |                                         |
|--|---|-----|--|-----------------------------------------|
|  | k | 2,0 |  | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$ |
|--|---|-----|--|-----------------------------------------|

|                                                         |            |       |                   |                                                                                                         |
|---------------------------------------------------------|------------|-------|-------------------|---------------------------------------------------------------------------------------------------------|
| Smallest width of the cross-section in the tensile area | $b_w$      | 326   | mm                |                                                                                                         |
| Reinforcement ratio for longitudinal reinforcement      | $\rho_l$   | 0,02  |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                               |
|                                                         | $C_{Rd,c}$ | 0,12  |                   | EN 1992-1-1/NB                                                                                          |
|                                                         | $v_{min}$  | 0,30  | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                              |
|                                                         |            |       |                   |                                                                                                         |
|                                                         | $V_{Rd,c}$ | 57584 | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w$<br>$* d \leq v_{min} * b_w * d$ |
|                                                         |            | 57,58 | kN                |                                                                                                         |
| Unity Check                                             | 0,43       | ≤     | 1,0               | No shear reinforcement required                                                                         |

#### K.2.4 Ultimate limit state – Transversal direction

##### Load distribution

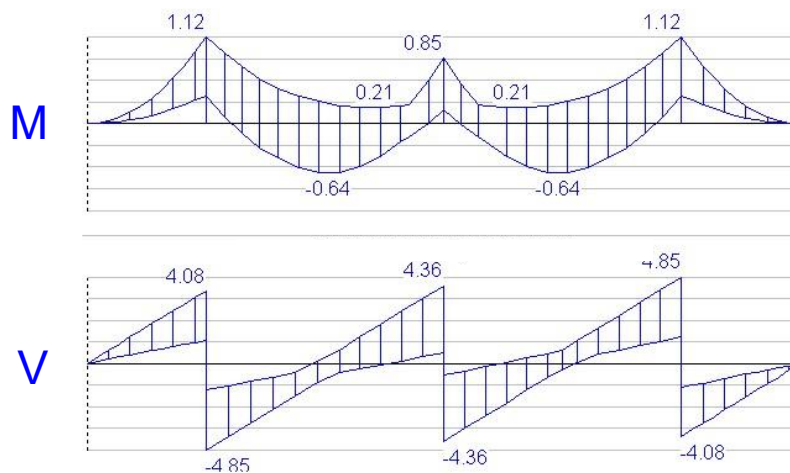


Figure K.22: Load distribution in transversal direction (enveloping fundamental combination using Technosoft Liggers)

|                                         |                 |      |     |  |
|-----------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment at top    | $M_{Ed,top}$    | 1,12 | kNm |  |
| Maximum acting bending moment at bottom | $M_{Ed,bottom}$ | 0,66 | kNm |  |
| Maximum acting shear force              | $V_{Ed}$        | 4,85 | kN  |  |

##### Bending moment reinforcement

##### Bending moment reinforcement at the top

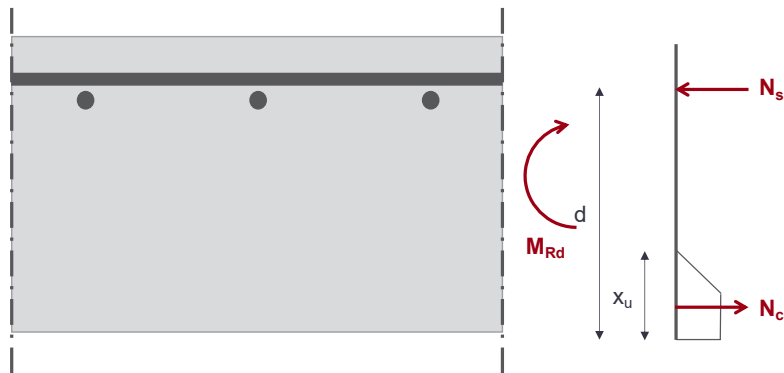


Figure K.23: Concrete cross-section top reinforcement

|                                  |          |         |     |                                                                                   |
|----------------------------------|----------|---------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 122932  | N   | $N_s = A_{st,t} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |         | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 8,20    | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
|                                  |          |         |     | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
| Bending moment resistance        | $M_{Rd}$ | 1819855 | Nmm | $N_s = A_{st,t} * f_{yd}$                                                         |
|                                  |          | 1,82    | kNm |                                                                                   |
| Unity Check                      | 0,62     | ≤       | 1,0 |                                                                                   |

#### Bending moment reinforcement at the bottom

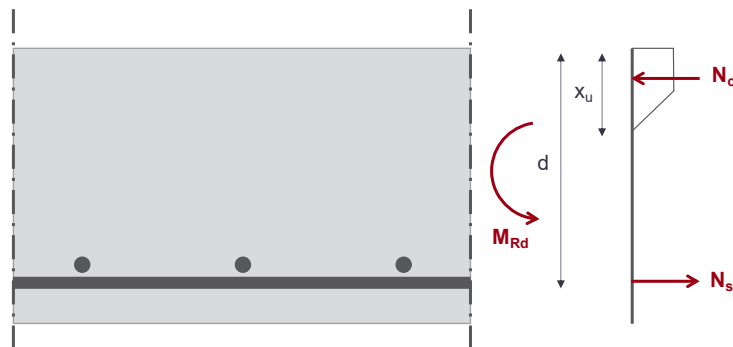


Figure K.24: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 54636  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,64   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 960478 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,96   | kNm | $N_s = A_{st,b} * f_{yd}$                                                         |
| Unity Check                      | 0,67     | ≤      | 1,0 |                                                                                   |

### Shear in web-flange interface

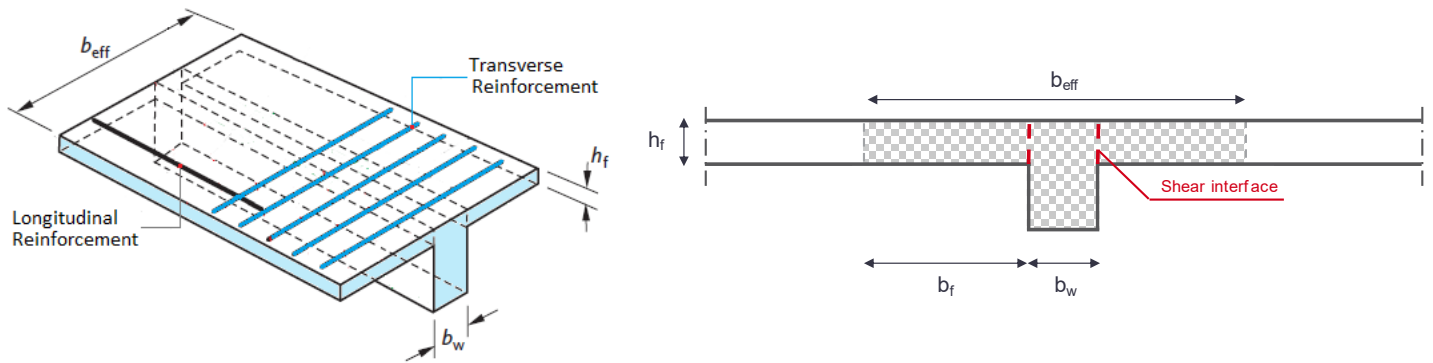


Figure K.25: Parameters for shear in the web-flange interface (Walraven, 2011)

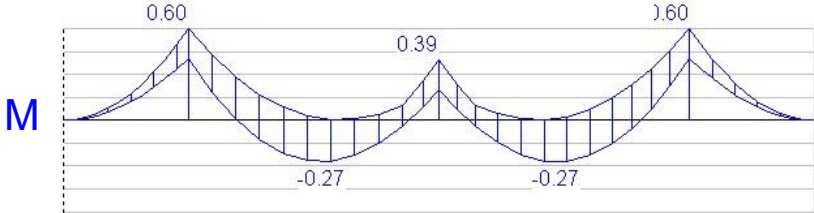
|                 |          |      |                   |                                                                   |
|-----------------|----------|------|-------------------|-------------------------------------------------------------------|
| Width of flange | $b_f$    | 382  | mm                |                                                                   |
| Shear stress    | $V_{Ed}$ | 0,28 | N/mm <sup>2</sup> | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$        |
|                 | $k$      | 0,4  |                   | EN 1992-1-1/NB                                                    |
| Chek            | 0,28     | ≤    | 0,54              | $v_{ed} \leq k * f_{ctd}$<br>No transverse reinforcement required |

### K.2.5 Serviceability limit state

#### Reinforcement for crack control

##### Minimum areas of reinforcement

|                                                                                                                          |                 |       |                   |                                                        |
|--------------------------------------------------------------------------------------------------------------------------|-----------------|-------|-------------------|--------------------------------------------------------|
| Absolute value of the maximum stress permitted in the reinforcement immediately after the formation of the crack         | $\sigma_s$      | 500   | N/mm <sup>2</sup> | EN 1992-1-1                                            |
| Coefficient which takes account of the stress distribution within the section immediately prior to cracking              | $k_c$           | 0,4   |                   | EN 1992-1-1                                            |
| Mean value of the tensile strength of the concrete effective at the times when the cracks may first be expected to occur | $f_{ct,eff}$    | 2,9   | N/mm <sup>2</sup> | EN 1992-1-1                                            |
| Coefficient which allows for the effect of non-uniform self-equilibrating                                                |                 |       |                   |                                                        |
| Slab                                                                                                                     | $k$             | 0,65  |                   | EN 1992-1-1                                            |
| Rib                                                                                                                      | $k$             | 1,00  |                   | EN 1992-1-1                                            |
| Area of concrete within the tensile zone                                                                                 |                 |       |                   |                                                        |
| Rib (longitudinal direction)                                                                                             | $A_{ct,r}$      | 27710 | mm <sup>2</sup>   |                                                        |
| Slab with reinforcement at the top (transversal direction)                                                               | $A_{ct,t,t}$    | 18000 | mm <sup>2</sup>   |                                                        |
| Slab with reinforcement at the bottom (transversal direction)                                                            | $A_{ct,t,b}$    | 18000 | mm <sup>2</sup>   |                                                        |
| Minimum area of reinforcement                                                                                            |                 |       |                   |                                                        |
| Rib in longitudinal direction                                                                                            | $A_{s,min,l,r}$ | 64    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$ |
| Slab in transversal direction, top                                                                                       | $A_{s,min,t,t}$ | 27    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$ |
| Slab in transversal direction, bottom                                                                                    | $A_{s,min,t,b}$ | 27    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$ |

|                                                                                                         |              |       |                   |                                                                                      |
|---------------------------------------------------------------------------------------------------------|--------------|-------|-------------------|--------------------------------------------------------------------------------------|
|                                                                                                         |              |       |                   |                                                                                      |
| The minimum areas or reinforcement are included in the reinforcement requirements in Appendix K.2.6     |              |       |                   |                                                                                      |
|                                                                                                         |              |       |                   |                                                                                      |
| <b>Restrictions for bar diameters and spacing</b>                                                       |              |       |                   |                                                                                      |
| Limit value crack width                                                                                 | $W_{\max}$   | 0,4   | mm                | EN 1992-1-1/NB                                                                       |
|                                                                                                         |              |       |                   |                                                                                      |
| <b>Longitudinal direction</b>                                                                           |              |       |                   |                                                                                      |
| Bending moment in SLS                                                                                   | $M_{Efreq}$  | 20,13 | kNm               | $M_{Ed} = \frac{1}{8} q_{SLS,l} l^2$                                                 |
| Bending moment resistance                                                                               | $M_{Rd}$     | 48,52 | kNm               |                                                                                      |
| Steel stress                                                                                            | $\sigma_s$   | 180   | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
|                                                                                                         |              |       |                   |                                                                                      |
| Maximum bar size                                                                                        | $\varphi'_s$ | 35    | mm                | EN 1992-1-1                                                                          |
| Adapted maximum bar size                                                                                | $\varphi_s$  | 31    | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
|                                                                                                         |              |       |                   |                                                                                      |
| Check $\varphi_s > \varphi_l$                                                                           | 31           | mm    | >                 | 6 mm                                                                                 |
|                                                                                                         |              |       |                   |                                                                                      |
| <b>Transversal direction</b>                                                                            |              |       |                   |                                                                                      |
|                     |              |       |                   |                                                                                      |
| Figure K.26: Load distribution in transversal direction (frequent combination using Technosoft Liggers) |              |       |                   |                                                                                      |
| Bending moment SLS, top                                                                                 | $M_{Efreq}$  | 0,60  | kNm               |                                                                                      |
| Bending moment SLS, bottom                                                                              | $M_{Efreq}$  | 0,27  | kNm               |                                                                                      |
|                                                                                                         |              |       |                   |                                                                                      |
| Bending moment resistance, top                                                                          | $M_{Rd}$     | 1,82  | kNm               |                                                                                      |
| Bending moment resistance, bottom                                                                       | $M_{Rd}$     | 0,96  | kNm               |                                                                                      |
|                                                                                                         |              |       |                   |                                                                                      |
| Steel stress, top                                                                                       | $\sigma_s$   | 143   | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
| Steel stress, bottom                                                                                    | $\sigma_s$   | 122   | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
|                                                                                                         |              |       |                   |                                                                                      |
| Maximum bar size, top                                                                                   | $\varphi'_s$ | 43    | mm                | EN 1992-1-1                                                                          |
| Maximum bar size, bottom                                                                                | $\varphi'_s$ | 48    | mm                | EN 1992-1-1                                                                          |
|                                                                                                         |              |       |                   |                                                                                      |
| Adapted maximum bar size, top                                                                           | $\varphi_s$  | 9     | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
| Adapted maximum bar size, bottom                                                                        | $\varphi_s$  | 10    | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
|                                                                                                         |              |       |                   |                                                                                      |
| Check $\varphi_s > \varphi_{t,t}$                                                                       | 9            | mm    | >                 | 6 mm                                                                                 |



|                                           |              |          |   |                                                                                                                                                                                                    |
|-------------------------------------------|--------------|----------|---|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Check $\varphi_s > \varphi_{t,b}$         | 10           | mm       | > | 4 mm                                                                                                                                                                                               |
|                                           |              |          |   |                                                                                                                                                                                                    |
|                                           |              |          |   |                                                                                                                                                                                                    |
| <b>Slenderness for deflection control</b> |              |          |   |                                                                                                                                                                                                    |
| <b>Longitudinal direction</b>             |              |          |   |                                                                                                                                                                                                    |
| Reference reinforcement ratio             | $\rho_0$     | 0,005477 |   | $\rho_0 = 10^{-3} * \sqrt{f_{ck}}$                                                                                                                                                                 |
| Tension reinforcement ratio               | $\rho_l$     | 0,007166 |   | $\rho_l = \frac{A_{sl}}{A}$                                                                                                                                                                        |
| Factor for different structural systems   | K            | 1        |   | EN 1992-1-1                                                                                                                                                                                        |
| Compression reinforcement ratio           | $\rho'_l$    | 0        |   |                                                                                                                                                                                                    |
|                                           |              |          |   |                                                                                                                                                                                                    |
| Limit span/depth                          | $l/d$        | 17       |   | $\frac{l}{d}$ $= K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_l - \rho'_l} \right. \\ \left. + \frac{1}{12} \sqrt{f_{ck}} \sqrt{\frac{\rho'_l}{\rho_0}} \right] \text{ if } \rho_l > \rho_0$ |
| Corrective value for slenderness          |              | 1,72     |   | $\frac{310}{\sigma_s}$                                                                                                                                                                             |
| Adapted span/depth limit                  |              | 30       |   |                                                                                                                                                                                                    |
|                                           |              |          |   |                                                                                                                                                                                                    |
| Check                                     | $l/h$        | 30       | < | 30                                                                                                                                                                                                 |
|                                           |              |          |   |                                                                                                                                                                                                    |
| <b>Transversal direction</b>              |              |          |   |                                                                                                                                                                                                    |
| Tension reinforcement ratio, top          | $\rho_{t,t}$ | 0,007854 |   | $\rho_{t,t} = \frac{A_{st,t}}{A}$                                                                                                                                                                  |
| Tension reinforcement ratio, bottom       | $\rho_{t,b}$ | 0,003491 |   | $\rho_{t,b} = \frac{A_{st,b}}{A}$                                                                                                                                                                  |
|                                           |              |          |   |                                                                                                                                                                                                    |
| Factor for different structural systems   | K            | 1,5      |   | EN 1992-1-1                                                                                                                                                                                        |
| Compression reinforcement ratio           | $\rho'_l$    | 0        |   |                                                                                                                                                                                                    |
|                                           |              |          |   |                                                                                                                                                                                                    |
| Limit span/depth, top                     | $l/d$        | 25       |   | $\frac{l}{d}$ $= K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t - \rho'_t} \right. \\ \left. + \frac{1}{12} \sqrt{f_{ck}} \sqrt{\frac{\rho'_t}{\rho_0}} \right] \text{ if } \rho_t > \rho_0$ |
| Limit span/depth, bottom                  | $l/d$        | 47       |   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t} \right. \\ \left. + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$  |
|                                           |              |          |   |                                                                                                                                                                                                    |

|                                          |     |      |   |                        |
|------------------------------------------|-----|------|---|------------------------|
| Corrective value for slenderness, top    |     | 2,16 |   | $\frac{310}{\sigma_s}$ |
| Corrective value for slenderness, bottom |     | 2,54 |   | $\frac{310}{\sigma_s}$ |
|                                          |     |      |   |                        |
| Check, top                               | l/h | 31   | < | 54                     |
| Check, bottom                            | l/h | 31   | < | 120                    |

## K.2.6 Detailing reinforcement requirements

| Minimum longitudinal tension reinforcement                          |                 |         |                 |                                                      |
|---------------------------------------------------------------------|-----------------|---------|-----------------|------------------------------------------------------|
| Section Modulus                                                     | W               | 2987439 | mm <sup>3</sup> |                                                      |
| Minimum principal reinforcement area (1)                            | $A_{s,min,1}$   | 3371516 | mm <sup>2</sup> | $A_{s,min,1} = \frac{f_{ctm} * W}{f_{yd} * 0.9 * d}$ |
| Required reinforcement area for ULS                                 | $A_s$           | 516     | mm <sup>2</sup> | $A_s = \frac{M_{Ed}}{f_{yd} * 0.9 * d}$              |
| Minimum principal reinforcement area (2)                            | $A_{s,min,2}$   | 645     | mm <sup>2</sup> | $A_{s,min,2} = 1.25 A_s$                             |
| Minimum principal reinforcement area                                | $A_{s,min}$     | 645     | mm <sup>2</sup> | $A_{s,min} = \min[A_{s,min,1}; A_{s,min,2}]$         |
|                                                                     |                 |         |                 |                                                      |
| Maximum reinforcement area                                          |                 |         |                 |                                                      |
| Longitudinal direction                                              |                 |         |                 |                                                      |
| Cross-sectional area of concrete                                    | $A_c$           | 94688,8 | mm <sup>2</sup> | $A_c = b_{eff} * h_s + b_r * h_r$                    |
| Maximum reinforcement area                                          | $A_{s,max}$     | 3788    | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |
|                                                                     |                 |         |                 |                                                      |
| Transversal direction                                               |                 |         |                 |                                                      |
| Cross-sectional area of concrete                                    | $A_c$           | 36000   | mm <sup>2</sup> | $A_c = h_s * [1 m]$                                  |
| Maximum reinforcement area                                          | $A_{s,max}$     | 1440    | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |
|                                                                     |                 |         |                 |                                                      |
| Minimum reinforcement spacing                                       |                 |         |                 |                                                      |
|                                                                     | $k_1$           | 1       |                 | EN 1992-1-1/NB                                       |
| Minimum reinforcement spacing (1) longitudinal reinforcement        | $s_{min,1,l}$   | 6       | mm              | $s_{min,1} = k_1 * \varphi_l$                        |
| Minimum reinforcement spacing (1) transversal reinforcement, top    | $s_{min,1,t,t}$ | 6       | mm              | $s_{min,1} = k_1 * \varphi_{t,t}$                    |
| Minimum reinforcement spacing (1) transversal reinforcement, bottom | $s_{min,1,t,b}$ | 4       | mm              | $s_{min,1} = k_1 * \varphi_{t,b}$                    |
|                                                                     |                 |         |                 |                                                      |
| Maximum size of aggregate                                           | $d_g$           | 16      | mm              | Assumption                                           |
|                                                                     | $k_2$           | 5       |                 | EN 1992-1-1/NB                                       |
| Minimum reinforcement spacing (2)                                   | $s_{min,2}$     | 21      | mm              | $s_{min,2} = d_g + k_2$                              |
|                                                                     |                 |         |                 |                                                      |
| Minimum reinforcement spacing longitudinal reinforcement            | $s_{min,l}$     | 21      | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 mm]$        |
| Minimum reinforcement spacing transversal reinforcement, top        | $s_{min,t,t}$   | 21      | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 mm]$        |
| Minimum reinforcement spacing transversal reinforcement, bottom     | $s_{min,t,b}$   | 21      | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 mm]$        |
|                                                                     |                 |         |                 |                                                      |
| Maximum reinforcement spacing                                       |                 |         |                 |                                                      |

|                                                           |                     |     |    |                                                   |
|-----------------------------------------------------------|---------------------|-----|----|---------------------------------------------------|
| Maximum reinforcement spacing for principal reinforcement | $s_{max,principal}$ | 250 | mm | $s_{max,principal} = 2 * h_t \leq 250 \text{ mm}$ |
| Maximum reinforcement spacing for secondary reinforcement | $s_{max,secondary}$ | 108 | mm | $s_{max,secondary} = 3 * h_s \leq 400 \text{ mm}$ |
|                                                           |                     |     |    |                                                   |

### Check

#### Longitudinal reinforcement

|                  |     |                 |   |     |                 |   |      |                 |
|------------------|-----|-----------------|---|-----|-----------------|---|------|-----------------|
| Area of rebar    | 645 | mm <sup>2</sup> | < | 679 | mm <sup>2</sup> | < | 3788 | mm <sup>2</sup> |
| Spacing of rebar | 21  | mm              | < | 45  | mm              | < | 250  | mm              |
|                  |     |                 |   |     |                 |   |      |                 |

#### Transversal reinforcement

|                         |    |                 |   |     |                 |   |      |                 |
|-------------------------|----|-----------------|---|-----|-----------------|---|------|-----------------|
| Area of rebar top       | 27 | mm <sup>2</sup> | < | 283 | mm <sup>2</sup> | < | 1440 | mm <sup>2</sup> |
| Spacing of rebar top    | 21 | mm              | < | 100 | mm              | < | 108  | mm              |
|                         |    |                 |   |     |                 |   |      |                 |
| Area of rebar bottom    | 27 | mm <sup>2</sup> | < | 126 | mm <sup>2</sup> | < | 1440 | mm <sup>2</sup> |
| Spacing of rebar bottom | 21 | mm              | < | 100 | mm              | < | 108  | mm              |

### K.2.7 Rib openings

| Input                                     |           |       |                 |                                           |
|-------------------------------------------|-----------|-------|-----------------|-------------------------------------------|
| Height slab                               | $h_s$     | 36    | mm              |                                           |
| Height rib                                | $h_r$     | 22,5  | mm              | $h_{r,o} = \frac{h_r - 125}{2}$           |
| Total height                              | $h_t$     | 58,5  | mm              | $h_t = h_s + h_{r,o}$                     |
|                                           |           |       |                 |                                           |
| Nominal cover                             | $c_{nom}$ | 15    | mm              |                                           |
| Diameter longitudinal reinforcement       | $\phi_l$  | 6     | mm              |                                           |
| Number of longitudinal reinforcement bars | $n$       | 24    |                 |                                           |
| Surface area longitudinal reinforcement   | $A_{sl}$  | 679   | mm <sup>2</sup> | $A_{sl} = n * \frac{1}{4} \pi \phi_l^2$   |
| Spacing of longitudinal reinforcement     | $s_l$     | 45    | mm              | $s_l = \frac{b_r}{n}$                     |
| Diameter stirrups                         | $\phi_s$  | 6     | mm              |                                           |
| Surface area stirrups                     | $A_{sw}$  | 28,27 | mm <sup>2</sup> | $A_{sw} = n * \frac{1}{4} \pi \phi_s^2$   |
| Effective height of the cross-section     | $d_l$     | 34,5  | mm              | $d = h - c - \phi_s - \frac{1}{2} \phi_l$ |
|                                           |           |       |                 |                                           |
| Load distribution                         |           |       |                 |                                           |

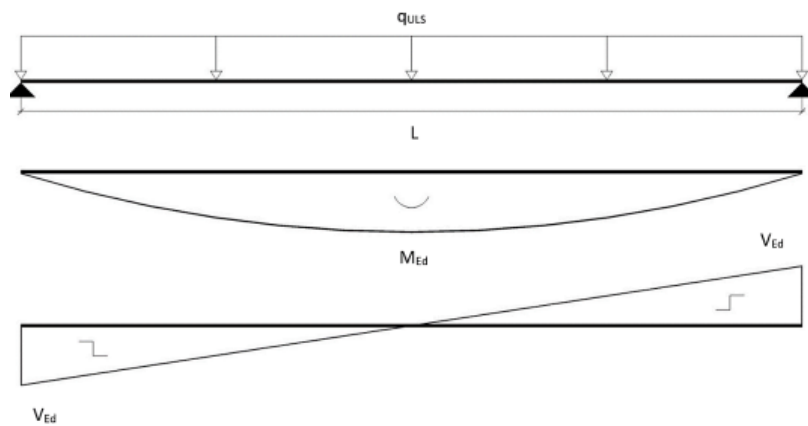


Figure K.27: Load distribution in the longitudinal direction

|                               |          |       |     |                                             |
|-------------------------------|----------|-------|-----|---------------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 3,23  | kNm | See unity check longitudinal bending moment |
| Maximum acting shear force    | $V_{Ed}$ | 24,88 | kN  | $V_{Ed} = \frac{1}{2} q l$                  |

### Bending moment reinforcement

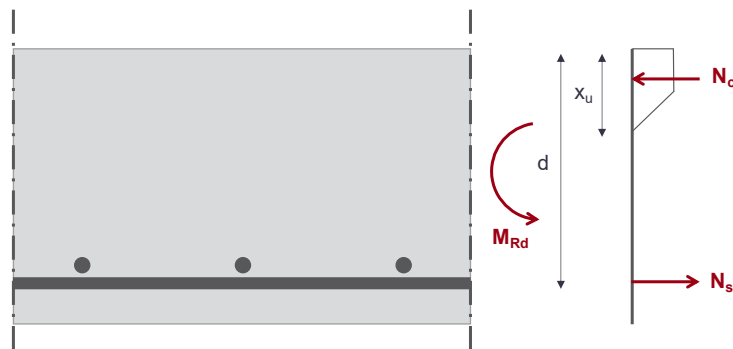


Figure K.28: Concrete cross-section

|                                                                    |          |             |            |                                                                              |
|--------------------------------------------------------------------|----------|-------------|------------|------------------------------------------------------------------------------|
| Rebar tensile force                                                | $N_s$    | 295037      | N          | $N_s = A_{sl} * f_{yd}$                                                      |
| Concrete compressive force                                         | $N_c$    |             | N          | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                 |
| Concrete compressive zone height                                   | $x_u$    | 60,33       | mm         | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$ |
| Bending moment resistance                                          | $M_{Rd}$ | 323639<br>7 | Nmm<br>kNm | $M_{Rd} = N_s * (d - 0.39x_u)$                                               |
| Unity Check                                                        | 1,00     | ≤           | 1,0        |                                                                              |
| Distance from the end of the beam where the opening can be located | x        | 0,133       | m          | $\frac{qlx}{2} - \frac{qx^2}{2} - M_{Ed} = 0$                                |

### Shear reinforcement

### Minimal reinforcement

|                                                                                  |               |         |                     |                                                                                                    |
|----------------------------------------------------------------------------------|---------------|---------|---------------------|----------------------------------------------------------------------------------------------------|
|                                                                                  | k             | 2,0     |                     | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                            |
| Smallest width of the cross-section in the tensile area                          | $b_w$         | 326     | mm                  |                                                                                                    |
| Reinforcement ratio for longitudinal reinforcement                               | $\rho_l$      | 0,060   |                     | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                          |
|                                                                                  | $C_{Rd,c}$    | 0,12    |                     | EN 1992-1-1/NB                                                                                     |
|                                                                                  | $v_{min}$     | 0,30    | N/mm <sup>2</sup>   | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                         |
|                                                                                  |               |         |                     |                                                                                                    |
|                                                                                  | $V_{Rd,c}$    | 15269   | N                   | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w * d \leq v_{min} * b_w * d$ |
|                                                                                  |               | 15      | kN                  | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                         |
|                                                                                  |               |         |                     |                                                                                                    |
| Unity Check                                                                      | 1,63          | ≤       | 1,0                 | Shear reinforcement required at the openings                                                       |
|                                                                                  |               |         |                     |                                                                                                    |
| <b>Maximum resistance</b>                                                        |               |         |                     |                                                                                                    |
| Coefficient taking into account the state of the stress in the compression chord | $\alpha_{cw}$ | 1       |                     | EN 1992-1-1/NB                                                                                     |
| Strength reduction factor for concrete cracked in shear                          | $v_1$         | 0,6     |                     | EN 1992-1-1/NB                                                                                     |
| Angle of the inclined struts                                                     | $\theta$      | 45      | °                   | Assumption                                                                                         |
|                                                                                  |               |         |                     |                                                                                                    |
| Limit value for shear resistance                                                 | $V_{Rd,max}$  | 60733,8 | N                   | $V_{Rd,max} = \alpha_{cw} * b_w * z * v_1 * f_{cd} / (\cot(\theta) + \tan(\theta))$                |
|                                                                                  |               | 61      | kN                  |                                                                                                    |
|                                                                                  |               |         |                     |                                                                                                    |
| Unity Check                                                                      | 0,41          | ≤       | 1,0                 | The cross-section is able to take the shear forces                                                 |
|                                                                                  |               |         |                     |                                                                                                    |
| <b>Required shear reinforcement</b>                                              |               |         |                     |                                                                                                    |
|                                                                                  | $A_{sw}/s_w$  | 1,84    | mm <sup>2</sup> /mm | $\frac{A_{sw}}{s_w} = \frac{V_{Ed} * \tan(\theta)}{z * f_{yd}}$                                    |
| Spacing of stirrups                                                              | $s_w$         | 15,34   | mm                  |                                                                                                    |

### K.2.8 Check of manual calculations

The previous calculations are manual calculations done using Microsoft Excel. To ensure the accuracy of these calculations, a number of the manually calculated values are checked using Technosoft Construct. The results of the manual calculations and the Technosoft output are in the same order of magnitude and therefore correspond sufficiently.

| Bending moment resistance – Longitudinal direction |          |       |     |
|----------------------------------------------------|----------|-------|-----|
| Manual calculation                                 | $M_{Rd}$ | 48,52 | kNm |
| Technosoft output                                  | $M_{Rd}$ | 51,1  | kNm |

### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                            |
|---------------------------|--------------------------------------------|
| Elementtype               | : Balk                                     |
| Betonkwaliteit            | : C30/37                                   |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram        |
| Doorsnede vorm            | : T2                                       |
| Afmetingen                | : b=1091 h=206 b1=326 h1=170 b2=326 h2=170 |
| Scheurvorming volgens art | : 7.3.4                                    |
| Referentieperiode         | : 50 jaar                                  |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevallige inklemming     | : nee                                  |

|                     |                         |
|---------------------|-------------------------|
| Toegepaste wapening | : Boven 0x12 Onder 24x6 |
| Breedte stortstleuf | : 50                    |

#### Betondekking

|                                 |                               |
|---------------------------------|-------------------------------|
| Milieu                          | : Boven XC1 Onder XC1         |
| Gestort tegen bestaand beton    | : Nee Nee                     |
| Element met plaatgeometrie      | : Nee Nee                     |
| Specifieke kwaliteitsbeheersing | : Nee Nee                     |
| Oneffen beton oppervlak         | : Nee Nee                     |
| Ondergrond                      | : Glad / N.v.t. Glad / N.v.t. |
| Constructieklasse               | : S3 S3                       |
| Grootste korrel                 | : 16.0                        |

|                                            |                       |
|--------------------------------------------|-----------------------|
| Hoofdwapening                              | : 1ste laag 1ste laag |
| Nominale dekking                           | : 17 15               |
| Toegepaste dekking                         | : 17 15               |
| Gelijkwaardige diameter                    | : 12 6                |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 12 10 0 6 10 0      |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 12 5 17 10 5 15     |

#### BELASTING

#### RESULTATEN

| Nr | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | Opm. |
|----|------------------|-------------------|----------------------|-----------------------|-------------------|-------------------|-----------------------|-----------------------|------|
| 1  | 0.0              | -37.9             | 0.0                  | 0.0                   | 2.7               | -51.1             | 0.0                   | -57.2                 |      |

Figure K.29: Output Technosoft Construct Bending reinforcement in the longitudinal direction

### Bending moment resistance – Transversal direction

|                           |            |      |     |
|---------------------------|------------|------|-----|
| Manual calculation top    | $M_{Rd,t}$ | 1,82 | kNm |
| Manual calculation bottom | $M_{Rd,b}$ | 0,96 | kNm |
| Technosoft output top     | $M_{Rd,t}$ | 1,8  | kNm |
| Technosoft output bottom  | $M_{Rd,b}$ | 0,9  | kNm |

**Toegepaste normen volgens Eurocode met Nederlandse NB**

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

**Controle hoofdwapening. (B)****GEOMETRIE**

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=36                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |

\* \* \* \* \*

**WAPENING**

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevallige inklemming     | : nee                                  |

|                     |        |       |
|---------------------|--------|-------|
|                     | Boven  | Onder |
| Toegepaste wapening | : 10x6 | : 0x4 |
| Breedte stortstleuf | : 50   |       |

**Betondekking**

|                                 |   |               |               |
|---------------------------------|---|---------------|---------------|
| Milieu                          | : | Boven<br>XC1  | Onder<br>XC1  |
| Gestort tegen bestaand beton    | : | Nee           | Nee           |
| Element met plaatgeometrie      | : | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing | : | Nee           | Nee           |
| Oneffen beton oppervlak         | : | Nee           | Nee           |
| Ondergrond                      | : | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse               | : | S3            | S3            |
| Grootste korrel                 | : | 16.0          |               |

|                                            |   |           |           |
|--------------------------------------------|---|-----------|-----------|
| Hoofdwapening                              | : | 1ste laag | 1ste laag |
| Nominale dekking                           | : | 15        | 15        |
| Toegepaste dekking                         | : | 15        | 15        |
| Gelijkwaardige diameter                    | : | 6         | 4         |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : | 6 10 0    | 4 10 0    |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : | 10 5 15   | 10 5 15   |

**BELASTING****RESULTATEN**

| Nr | Sterkte          |                   | Scheurvorming         |                       | Opm. |
|----|------------------|-------------------|-----------------------|-----------------------|------|
|    | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] |      |
| 1  | 0.0              | 1.2               | 0.0                   | -0.0                  |      |

Figure K.30: Output Technosoft Construct Bending reinforcement in transversal direction top



### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=36                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staal kwaliteit           | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalige inklemming      | : nee                                  |
| Toegepaste wapening       | : Boven 0x6 Onder 10x4                 |
| Breedte stort sleuf       | : 50                                   |

#### Betondekking

|                                 |                               |
|---------------------------------|-------------------------------|
| Milieu                          | : Boven XC1 Onder XC1         |
| Gestort tegen bestaand beton    | : Nee Nee                     |
| Element met plaat geometrie     | : Nee Nee                     |
| Specifieke kwaliteitsbeheersing | : Nee Nee                     |
| Oneffen beton oppervlak         | : Nee Nee                     |
| Ondergrond                      | : Glad / N.v.t. Glad / N.v.t. |
| Constructieklasse               | : S3 S3                       |
| Grootste korrel                 | : 16.0                        |

|                                            |                       |
|--------------------------------------------|-----------------------|
| Hoofdwapening                              | : 1ste laag 1ste laag |
| Nominale dekking                           | : 15 15               |
| Toegepaste dekking                         | : 15 15               |
| Gelijkwaardige diameter                    | : 6 4                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 6 10 0 4 10 0       |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 10 5 15 10 5 15     |

#### BELASTING

#### RESULTATEN

| Nr | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{Rd}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | Opm. |
|----|------------------|-------------------|----------------------|-----------------------|-------------------|-------------------|-----------------------|-----------------------|------|
| 1  | 0.0              | -0.7              | 0.0                  | 0.0                   | 0.5               | -0.9              | 0.0                   | -0.0                  | 167  |

Figure K.31: Output Technosoft Construct Bending reinforcement in transversal direction top

### Shear force resistance – Longitudinal direction

|                    |            |       |    |
|--------------------|------------|-------|----|
| Manual calculation | $V_{Rd,c}$ | 57,58 | kN |
| Technosoft output  | $V_{Rd,c}$ | 56,63 | kN |

**Toegepaste normen volgens Eurocode met Nederlandse NB**

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

**Dwarskracht en wringing. (B)****GEOMETRIE**

|                           |                                            |
|---------------------------|--------------------------------------------|
| Elementtype               | : Balk                                     |
| Betonkwaliteit            | : C30/37                                   |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram        |
| Doorsnede vorm            | : T2                                       |
| Afmetingen                | : b=1091 h=206 b1=326 h1=170 b2=326 h2=170 |
| Referentieperiode         | : 50 jaar                                  |

**WAPENING**

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Toevallige inklemming     | : nee                                  |
| Toegepaste wapening       | : Boven 0x6 Onder 24x6                 |
| Breedte stort sleuf       | : 50                                   |

**Betondekking**

|                                            |   |               |               |
|--------------------------------------------|---|---------------|---------------|
| Milieu                                     | : | Boven XC1     | Onder XC1     |
| Gestort tegen bestaand beton               | : | Nee           | Nee           |
| Element met plaatgeometrie                 | : | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing            | : | Nee           | Nee           |
| Oneffen beton oppervlak                    | : | Nee           | Nee           |
| Ondergrond                                 | : | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                          | : | S3            | S3            |
| Grootste korrel                            | : | 16.0          |               |
| Hoofdwapening                              | : | 2de laag      | 2de laag      |
| Nominale dekking                           | : | 15            | 15            |
| Toegepaste dekking                         | : | 22            | 20            |
| Gelijkwaardige diameter                    | : | 6             | 6             |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : | 6 10 0        | 6 10 0        |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : | 10 5 15       | 10 5 15       |

|                                            |                        |           |                                   |
|--------------------------------------------|------------------------|-----------|-----------------------------------|
| Beugel / Verdeelwapening                   | :                      | 1ste laag | 1ste laag                         |
| Nominale dekking                           | :                      | 15        | 15                                |
| Toegepaste dekking                         | :                      | 17        | 15                                |
| Gelijkwaardige diameter                    | :                      | 5         | 5                                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | :                      | 5 10 0    | 5 10 0                            |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | :                      | 10 5 15   | 10 5 15                           |
| Minimale beugelafstand                     | :                      | 50        | Theta [graden] : 21.8             |
| Uitg.p. inw.hefboomsarm z                  | :                      | 0,9*d     |                                   |
| <b>BELASTING</b>                           |                        |           |                                   |
| NEd                                        | [kN] :                 | 0.0       | MEd [kNm] : 0.0                   |
| VEd                                        | [kN] :                 | 24.9      | TEd [kNm] : 0.0                   |
| Q-permanent                                | [kN/m] :               | 0.0       | Veiligheidsklasse : 1             |
| Q-veranderlijk                             | [kN/m] :               | 0.0       | Gamma-permanent : 1.08            |
| L                                          | [m] :                  | 6.1       | Gamma-veranderlijk : 1.35         |
|                                            |                        |           | X [m] : 0.0                       |
| <b>RESULTATEN</b>                          |                        |           |                                   |
| Beugeldiameter                             | [mm] :                 | 5         | z [mm] : 164.70                   |
| Trekzijde                                  | :                      | Onder     | Wapeningsverhouding : 0.00340     |
| Dwarskracht                                |                        |           | Wringing                          |
| $V_{Rd,max}$                               | [kN] :                 | 263.27    | $T_{Rd,max}$ [kNm] : 26.54        |
| $V_{Ed}$                                   | [kN] :                 | 24.88     | $T_{Ed}$ [kNm] : 0.00             |
| $V_{Rd,c}$                                 | [kN] :                 | 56.63     | $T_{RD,c}$ [kNm] : 9.85           |
| A-opg                                      | [mm <sup>2</sup> /m] : | 0.00      | A-langs [mm <sup>2</sup> ] : 0.00 |
| A-bgl                                      | [mm <sup>2</sup> /m] : | 0.00      | A-bgl [mm <sup>2</sup> /m] : 0.00 |
| H.o.h. afstand                             | [mm] :                 | 300.0     | Aant. beugelsneden/drsn: 1        |

Figure K.32: Output Technosoft Construct shear reinforcement in the longitudinal direction

### K.3 Option A.ii: Prestressed long span with accessibility from the top

#### K.3.1 Input

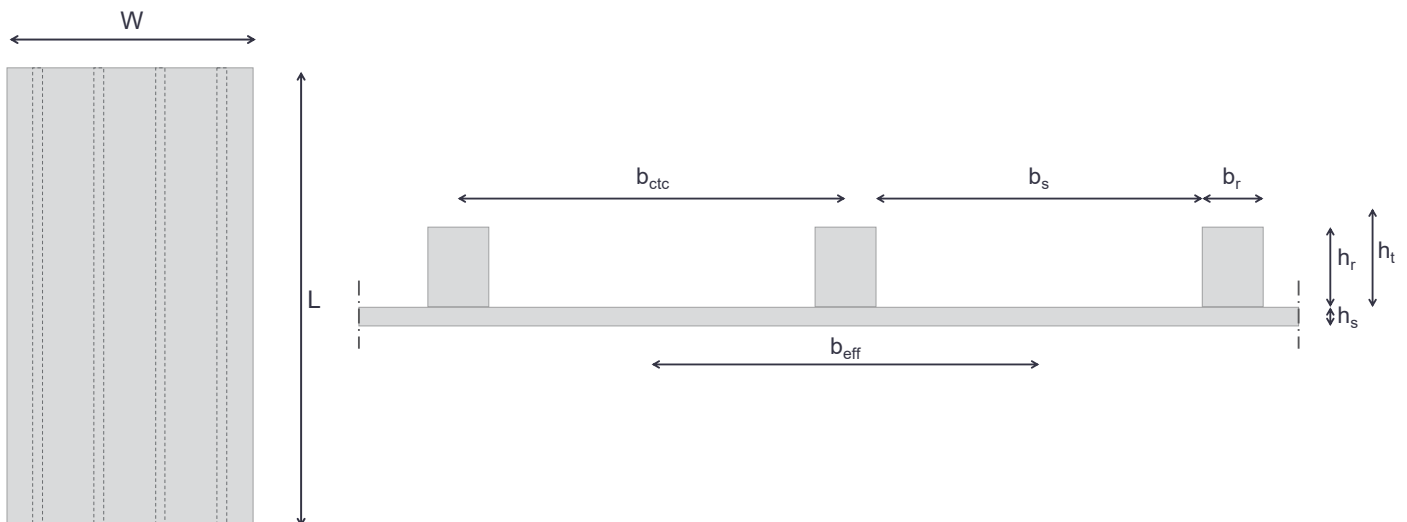


Figure K.33: Indication of the dimensions

| Dimensions     |       |      |    |                                                                                    |
|----------------|-------|------|----|------------------------------------------------------------------------------------|
| Span           | L     | 6100 | mm |                                                                                    |
| Width          | W     | 3300 | mm |                                                                                    |
| Number of ribs |       | 3    |    |                                                                                    |
| Height slab    | $h_s$ | 36   | mm | $\geq \max[\varphi_{t,t}; \varphi_{t,b}; \varphi_l; \varphi_p] + 2 * c_{nom} = 36$ |
| Height rib     | $h_r$ | 170  | mm | $\geq 170$ mm                                                                      |

|                                               |                  |        |                   |                                                 |
|-----------------------------------------------|------------------|--------|-------------------|-------------------------------------------------|
| Height rib at opening                         | $h_{r,o}$        | 22,5   | mm                | $h_{r,o} = \frac{h_r - 125}{2}$                 |
| Total height                                  | $h_t$            | 206    | mm                |                                                 |
| Total height at opening                       | $h_{t,o}$        | 58,5   | mm                |                                                 |
| Width rib                                     | $b_r$            | 100    | mm                |                                                 |
| Space between ribs                            | $b_s$            | 1000   | mm                | $\geq 170$ mm                                   |
| Centre to centre distance between ribs        | $b_{ctc}$        | 1100   | mm                | $b_{ctc} = b_r + b_s$                           |
| <b>Concrete properties</b>                    |                  |        |                   |                                                 |
| <b>C30/37</b>                                 |                  |        |                   |                                                 |
| Density                                       | $\rho_{rep}$     | 25     | kN/m <sup>3</sup> |                                                 |
| Characteristic cylinder strength              | $f_{ck}$         | 30     | N/mm <sup>2</sup> |                                                 |
| Partial safety factor concrete                | $\gamma_c$       | 1,5    |                   |                                                 |
| Design compressive strength                   | $f_{cd}$         | 20     | N/mm <sup>2</sup> |                                                 |
| Design tensile strength                       | $f_{ctd}$        | 1,35   | N/mm <sup>2</sup> |                                                 |
| Mean tensile strength                         | $f_{ctm}$        | 2,9    | N/mm <sup>2</sup> |                                                 |
| Young's modulus                               | $E_c$            | 33000  | N/mm <sup>2</sup> |                                                 |
| <b>Reinforcement properties</b>               |                  |        |                   |                                                 |
| <b>Longitudinal reinforcement</b>             |                  |        |                   |                                                 |
| Diameter longitudinal reinforcement           | $\varphi_l$      | 6      | mm                |                                                 |
| Number of longitudinal reinforcement bars     | $n$              | 5      |                   |                                                 |
| Surface area longitudinal reinforcement       | $A_{sl}$         | 141    | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$      |
| Spacing of longitudinal reinforcement         | $s_l$            | 182    | mm                | $s_l = \frac{b_{eff}}{n}$                       |
| Effective height of the cross-section         | $d_l$            | 186    | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$ |
| <b>Concrete cover</b>                         |                  |        |                   |                                                 |
| Minimum cover due to environmental conditions | $c_{min,dur}$    | 10     | mm                | XC1                                             |
| Minimum cover due to bond requirement         | $c_{min,b}$      | 6      | mm                | EN 1992-1-1                                     |
| Minimum cover                                 | $c_{min}$        | 10     | mm                |                                                 |
| Allowance in design for deviation             | $\Delta c_{dev}$ | 5      | mm                | EN 1992-1-1/NB                                  |
| Nominal cover                                 | $c_{nom}$        | 15     | mm                |                                                 |
| <b>Reinforcement steel</b>                    |                  |        |                   |                                                 |
| <b>B500 B</b>                                 |                  |        |                   |                                                 |
| Yield strength                                | $f_{yk}$         | 500    | N/mm <sup>2</sup> |                                                 |
| Partial safety factor steel                   | $\gamma_s$       | 1,15   |                   |                                                 |
| Design yield stress                           | $f_{yd}$         | 435    | N/mm <sup>2</sup> |                                                 |
| Young's modulus                               | $E_s$            | 200000 | N/mm <sup>2</sup> |                                                 |
| <b>Prestressing steel</b>                     |                  |        |                   |                                                 |

|                                         |             |      |                   |                                                                                              |
|-----------------------------------------|-------------|------|-------------------|----------------------------------------------------------------------------------------------|
| Y1670C                                  |             |      |                   | EN 10138-2                                                                                   |
| Characteristic tensile strength         | $f_{pk}$    | 1770 | N/mm <sup>2</sup> |                                                                                              |
| 0,1% proof-stress of prestressing steel | $f_{p0,1k}$ | 1593 | N/mm <sup>2</sup> |                                                                                              |
| Diameter of prestressing tendons        | $\varphi_p$ | 6    | mm                |                                                                                              |
| Number of prestressing tendons          | $n$         | 15   |                   |                                                                                              |
| Area of prestressing steel              | $A_p$       | 424  | mm <sup>2</sup>   | $A_p = n * \frac{1}{4} \pi \varphi_p^2$                                                      |
| Spacing of prestressing tendons         | $s_p$       | 61   | mm                | $s_p = \frac{b_{eff}}{n}$<br>$\leq \max[d_g + 5; 2\varphi_p; 20 \text{ mm}] = 21 \text{ mm}$ |

### K.3.2 Loads

| Permanent loads                                     |                |      |                   |                                                                             |
|-----------------------------------------------------|----------------|------|-------------------|-----------------------------------------------------------------------------|
| Slab                                                | $g_{slab}$     | 0,90 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                               |
| Rib                                                 | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                |
| Ceiling panels                                      | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                             |
| Building services                                   | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                        |
| Total deadload longitudinal direction               | $g_{k,l}$      | 1,97 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$ |
| Variable load                                       |                |      |                   |                                                                             |
| Variable floor load residential buildings           | $q_{res}$      | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                              |
| Movable partitions                                  | $q_{part}$     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                 |
| Total variable floor load                           | $q_{tot}$      | 2,55 | kN/m <sup>2</sup> |                                                                             |
| Total variable floor load in longitudinal direction | $q_{k,l}$      | 2,81 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                               |
| Load combination ULS                                |                |      |                   |                                                                             |
| Partial factor for permanent loads                  | $\gamma_G$     | 1,35 |                   | EN 1990/NB                                                                  |
| Partial factor for variable loads                   | $\gamma_Q$     | 1,5  |                   | EN 1990/NB                                                                  |
| Partial factor for prestressing                     | $\gamma_P$     | 1,2  |                   | EN 1992-1-1/NB                                                              |
| ULS load combination in longitudinal direction      | $q_{ULS,l}$    | 6,86 | kN/m              | EN 1990 6.10a                                                               |
| Load combination SLS                                |                |      |                   |                                                                             |
| Factor for frequent value of a variable action      | $\psi_{1,1}$   | 0,5  |                   | EN 1990                                                                     |
| SLS load combination in longitudinal direction      | $q_{SLS,l}$    | 3,37 | kN/m              | EN 1990 6.15a                                                               |

### K.3.3 Kern area

#### Kern area of the full cross-section

Normal force centre

|                               |             |         |       |                                    |       |       |  |
|-------------------------------|-------------|---------|-------|------------------------------------|-------|-------|--|
| From the top                  | $z_{nc}$    | 153     | mm    | $z_{NC} = \frac{ES_{\bar{z}}}{EA}$ |       |       |  |
| From the right                | $y_{nc}$    | 455     | mm    | $y_{NC} = \frac{ES_{\bar{y}}}{EA}$ |       |       |  |
|                               |             |         |       |                                    |       |       |  |
| Cross-sectional quantities    |             |         |       |                                    |       |       |  |
| Slab                          | distance z  | 35      | mm    | distance y                         | 0     | mm    |  |
| Rib                           |             | -68     | mm    |                                    | 0     | mm    |  |
|                               |             |         |       |                                    |       |       |  |
| Moments of inertia            |             |         |       |                                    |       |       |  |
| $I_{yy}$                      | 2274879667  | $mm^4$  |       |                                    |       |       |  |
| $I_{yz}$                      | 0           | $mm^4$  |       |                                    |       |       |  |
| $I_{zz}$                      | 163216970,9 | $mm^4$  |       |                                    |       |       |  |
|                               |             |         |       |                                    |       |       |  |
| Position of kern points       |             |         |       |                                    |       |       |  |
| line                          | $y_1$       | $1/y_1$ | $z_1$ | $1/z_1$                            | $e_y$ | $e_z$ |  |
| top                           | $\infty$    | 0       | -153  | -0,0065                            | 0     | 21    |  |
| bottom                        | $\infty$    | 0       | 53    | 0,0188                             | 0     | -62   |  |
|                               |             |         |       |                                    |       |       |  |
|                               |             |         |       |                                    |       |       |  |
| Distance from bottom to $k_b$ |             |         | 32    | mm                                 |       |       |  |
| Distance from bottom to $k_t$ |             |         | 115   | mm                                 |       |       |  |

| Kern area of the cross-section at rib opening |            |         |       |                                    |       |       |  |
|-----------------------------------------------|------------|---------|-------|------------------------------------|-------|-------|--|
| Normal force centre                           |            |         |       |                                    |       |       |  |
| From the top                                  | $z_{nc}$   | 39      | mm    | $z_{NC} = \frac{ES_{\bar{z}}}{EA}$ |       |       |  |
| From the right                                | $y_{nc}$   | 455     | mm    | $y_{NC} = \frac{ES_{\bar{y}}}{EA}$ |       |       |  |
|                                               |            |         |       |                                    |       |       |  |
| Cross-sectional quantities                    |            |         |       |                                    |       |       |  |
| Slab                                          | distance z | 2       | mm    | distance y                         | 0     | mm    |  |
| Rib                                           |            | -27     | mm    |                                    | 0     | mm    |  |
|                                               |            |         |       |                                    |       |       |  |
| Moments of inertia                            |            |         |       |                                    |       |       |  |
| $I_{yy}$                                      | 2262588000 | $mm^4$  |       |                                    |       |       |  |
| $I_{yz}$                                      | 0          | $mm^4$  |       |                                    |       |       |  |
| $I_{zz}$                                      | 5434302    | $mm^4$  |       |                                    |       |       |  |
|                                               |            |         |       |                                    |       |       |  |
| Position of kern points                       |            |         |       |                                    |       |       |  |
| line                                          | $y_1$      | $1/y_1$ | $z_1$ | $1/z_1$                            | $e_y$ | $e_z$ |  |
| top                                           | $\infty$   | 0       | -39   | -0,0259                            | 0     | 4,0   |  |
| bottom                                        | $\infty$   | 0       | 20    | 0,0503                             | 0     | -7,8  |  |
|                                               |            |         |       |                                    |       |       |  |
|                                               |            |         |       |                                    |       |       |  |
| Distance from bottom to $k_b$                 |            |         | 16    | mm                                 |       |       |  |
| Distance from bottom to $k_t$                 |            |         | 28    | mm                                 |       |       |  |

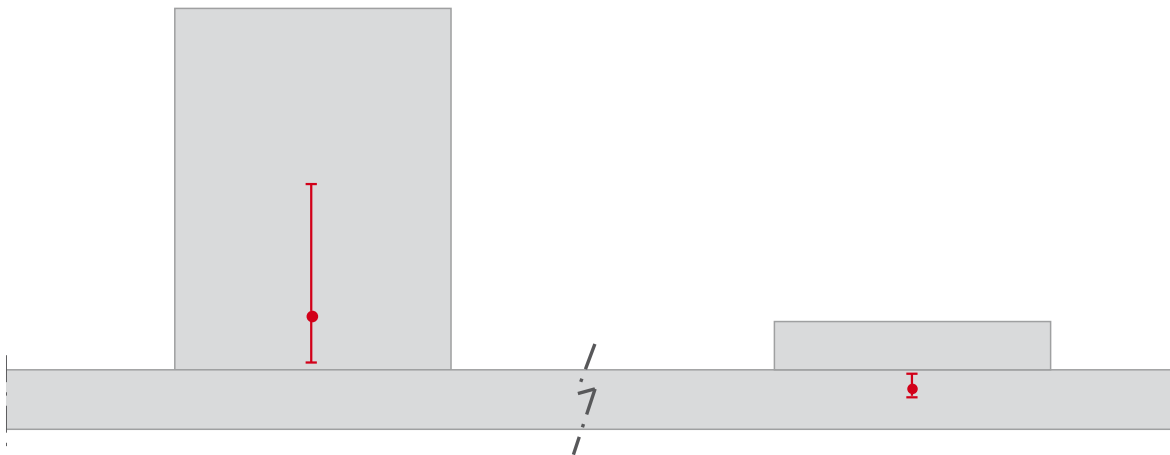


Figure K.34: Comparison of the kern areas for a full cross-section and the cross-section at the rib opening

### K.3.4 Preliminary partial prestressing calculations at the full cross-section

#### Choice of prestressing load

Chosen to remain uncracked under permanent load

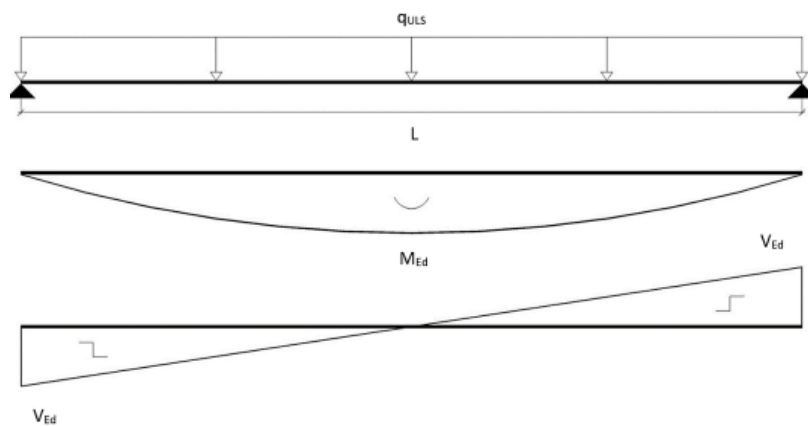


Figure K.35: Load distribution in the longitudinal direction

|                                                                  |       |    |     |                             |
|------------------------------------------------------------------|-------|----|-----|-----------------------------|
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 12 | kNm | $M_g = \frac{1}{8} q_g l^2$ |
|------------------------------------------------------------------|-------|----|-----|-----------------------------|

#### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                         |                                                                                                                                                                             |         |                 |                                                         |
|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|-----------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction | $A_c$                                                                                                                                                                       | 49760   | mm <sup>2</sup> |                                                         |
| Distance of tendon to the centre of gravity             | $e_p$                                                                                                                                                                       | 33      | mm              | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                           | $W_t$                                                                                                                                                                       | 1068096 | mm <sup>3</sup> |                                                         |
|                                                         | $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |         |                 |                                                         |



|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|-----------------|--------------------------|-------------------------------------------------------|-----------------|--|
| Prestressing force required                                                                                                                              | $P_{m,\infty,req}$<br>q | >               | 225264                   | N                                                     |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| <i>The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be</i> | 20%                     |                 | (Walraven & Braam, 2019) |                                                       |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| Initial prestressing force required                                                                                                                      | $P_{m,0,req}$<br>q      | 281580          | N                        | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                  |                 |  |
|                                                                                                                                                          | k <sub>7</sub>          | 0,75            |                          | EN 1992-1-1/NB                                        |                 |  |
|                                                                                                                                                          | k <sub>8</sub>          | 0,85            |                          | EN 1992-1-1/NB                                        |                 |  |
| Initial prestressing steel stress                                                                                                                        | $\sigma_{pm,0}$         | 1328            | N/mm <sup>2</sup>        | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |                 |  |
| Minimum required amount of prestressing steel                                                                                                            | $A_{p,req}$             | 212             | mm <sup>2</sup>          | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm0}}$            |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| Amount of prestressing steel stress                                                                                                                      | 442                     | mm <sup>2</sup> | ≥                        | 212                                                   | mm <sup>2</sup> |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| Prestressing steel stress                                                                                                                                | $\sigma_{pm,\infty}$    | 1062            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$            |                 |  |
| Working prestressing force                                                                                                                               | $P_{m,\infty}$          | 450410          | N                        | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$             |                 |  |
| Initial prestressing force                                                                                                                               | $P_{m,0}$               | 563013          | N                        | $P_{m,0} = \sigma_{pm,0} * A_p$                       |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| Determination of the required amount of reinforcing steel                                                                                                |                         |                 |                          |                                                       |                 |  |
| Bending moment due to permanent and variable load                                                                                                        | $M_{g+q}$               | 32              | kNm                      | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$                   |                 |  |
| Bending moment due to prestressing                                                                                                                       | $M_p$                   | 18003300,4<br>3 | Nmm                      | $M_p = \gamma_P * P_{m,\infty} * e_p$                 |                 |  |
|                                                                                                                                                          |                         | 18              | kNm                      |                                                       |                 |  |
| Total bending moment                                                                                                                                     | $M_{tot}$               | 14              | kNm                      | $M_{tot} = M_{g+q} - M_p$                             |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| <i>Time dependent losses are estimated to be</i>                                                                                                         | 10%                     |                 | (Walraven & Braam, 2019) |                                                       |                 |  |
| <i>Friction loss is assumed to be</i>                                                                                                                    | 10%                     |                 | (Walraven & Braam, 2019) |                                                       |                 |  |
| Working prestressing steel stress                                                                                                                        | $\sigma_{pm,\infty}$    | 1075            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$      |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |
| <i>It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit (f<sub>p0,1k</sub>)</i>                         |                         |                 |                          |                                                       |                 |  |
|                                                                                                                                                          | $\Delta\sigma$          | 518             | N/mm <sup>2</sup>        | $f_{p0,1k} - \sigma_{pm,\infty}$                      |                 |  |
|                                                                                                                                                          |                         |                 |                          |                                                       |                 |  |

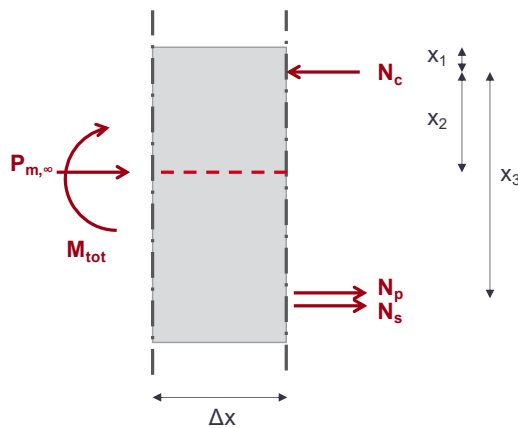


Figure K.36: Total bending moment around the resulting concrete compressive

|                                                              |                     |                                                                     |                    |                                                                                                                              |
|--------------------------------------------------------------|---------------------|---------------------------------------------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                              | X <sub>1</sub>      | 50                                                                  | mm                 |                                                                                                                              |
|                                                              | X <sub>2</sub>      | 103                                                                 | mm                 |                                                                                                                              |
|                                                              | X <sub>3</sub>      | 136                                                                 | mm                 | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                           | N <sub>p</sub>      | 219575                                                              | N                  | $N_p = \Delta \sigma * A_p$                                                                                                  |
| Working prestressing force                                   | P <sub>m,∞</sub>    | 456040                                                              | N                  | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                          | N <sub>s</sub>      | -564020                                                             | N                  | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Required reinforcement area                                  | A <sub>sl,req</sub> | -1128                                                               | mm <sup>2</sup>    | $N_s = f_{yk} * A_{sl}$                                                                                                      |
|                                                              |                     | A <sub>sl</sub> < 0 mm <sup>2</sup> : minimum reinforcement applies |                    |                                                                                                                              |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Detailing of reinforcement                                   |                     |                                                                     |                    |                                                                                                                              |
| Minimum reinforcement is required                            |                     |                                                                     |                    |                                                                                                                              |
|                                                              | α <sub>e</sub>      | 7                                                                   |                    | (Walraven & Braam, 2019)                                                                                                     |
| Minimum reinforcement ratio                                  | ρ <sub>min</sub>    | 0,6997%                                                             |                    | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$                                                                   |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Smallest width of the cross-section in the tensile area      | b <sub>w</sub>      | 100                                                                 | mm                 |                                                                                                                              |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Applied reinforcement ratio                                  | ρ                   | 0,752%                                                              | ≤ ρ <sub>min</sub> | $\rho_l = \frac{A_{sl}}{b_w d}$                                                                                              |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Control of the crack width (SLS)                             |                     |                                                                     |                    |                                                                                                                              |
| Maximum crack width                                          | W <sub>max</sub>    | 30                                                                  | mm                 | EN 1992-1-1/NB                                                                                                               |
|                                                              |                     |                                                                     |                    |                                                                                                                              |
| Ratio of bond strength of prestressing and reinforcing steel | ξ                   | 0,70                                                                |                    | EN 1992-1-1                                                                                                                  |
| Bonding factor of prestressing steel                         | ξ <sub>1</sub>      | 0,84                                                                |                    | $\xi_1 = \sqrt{\xi * \frac{\varphi_s}{\varphi_p}}$                                                                           |
|                                                              |                     |                                                                     |                    |                                                                                                                              |

|                                                   |                 |            |     |                                                                                                                                                                                                            |
|---------------------------------------------------|-----------------|------------|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bending moment due to permanent and variable load | $M_{g+q}$       | 16         | kNm | $M_{g+q} = \frac{1}{8} q_{SLs} l^2$                                                                                                                                                                        |
| Bending moment due to prestressing                | $M_p$           | 15002750   | Nmm | $M_p = P_{m,\infty} * e_p$                                                                                                                                                                                 |
|                                                   |                 | 15         | kNm |                                                                                                                                                                                                            |
| Total bending moment                              | $M_{tot}$       | 1          | kNm | $M_{tot} = M_{g+q} - M_p$                                                                                                                                                                                  |
|                                                   |                 |            |     |                                                                                                                                                                                                            |
| Strain in steel                                   | $\varepsilon_s$ | -0,0034219 |     | $\sum M = 0$ $\Leftrightarrow \varepsilon_s (A_s + \xi_1 A_p) E_s * x_3 + P_{m,\infty} * x_2 = M_{tot}$ $\Leftrightarrow \varepsilon_s = \frac{M_{tot} - P_{m,\infty} * x_2}{(A_s + \xi_1 A_p) E_s * x_3}$ |
| The cross-section is not cracked in SLS           |                 |            |     |                                                                                                                                                                                                            |

### K.3.5 Preliminary partial prestressing calculations at rib opening

#### Choice of prestressing load

Chosen to remain uncracked under permanent load

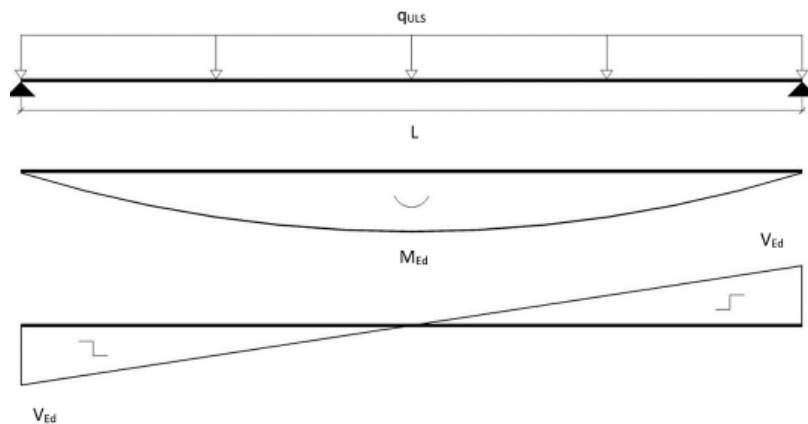


Figure K.37: Load distribution in the longitudinal direction

|                                                                  |       |     |     |                                  |
|------------------------------------------------------------------|-------|-----|-----|----------------------------------|
| Distance from the end of the beam that has a rib opening         | x     | 232 | mm  |                                  |
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 1,8 | kNm | $M(x) = \frac{q_g x}{2} (l - x)$ |
|                                                                  |       |     |     |                                  |

#### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                                                                                                                                             |       |        |                 |                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|--------|-----------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction                                                                                                                     | $A_c$ | 35010  | mm <sup>2</sup> |                                                         |
| Distance of tendon to the centre of gravity                                                                                                                                 | $e_p$ | 0      | mm              | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                                                                                                                                               | $W_t$ | 140711 | mm <sup>3</sup> |                                                         |
|                                                                                                                                                                             |       |        |                 |                                                         |
| $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |       |        |                 |                                                         |

|                                                                                                                                                          |                      |                 |                          |                                                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-----------------|--------------------------|-------------------------------------------------------|
| Prestressing force required                                                                                                                              | $P_{m,\infty,req}$   | >               | 449270                   | N                                                     |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| <i>The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be</i> | 20%                  |                 | (Walraven & Braam, 2019) |                                                       |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| Initial prestressing force required                                                                                                                      | $P_{m,0,req}$        | 561587          | N                        | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                  |
|                                                                                                                                                          | $k_7$                | 0,75            |                          | EN 1992-1-1/NB                                        |
|                                                                                                                                                          | $k_8$                | 0,85            |                          | EN 1992-1-1/NB                                        |
| Initial prestressing steel stress                                                                                                                        | $\sigma_{pm,0}$      | 1328            | N/mm <sup>2</sup>        | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |
| Minimum required amount of prestressing steel                                                                                                            | $A_{p,req}$          | 423             | mm <sup>2</sup>          | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm0}}$            |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| Amount of prestressing steel stress                                                                                                                      | 424                  | mm <sup>2</sup> | ≥                        | 423 mm <sup>2</sup>                                   |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| Prestressing steel stress                                                                                                                                | $\sigma_{pm,\infty}$ | 1062            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$            |
| Working prestressing force                                                                                                                               | $P_{m,\infty}$       | 450410          | N                        | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$             |
| Initial prestressing force                                                                                                                               | $P_{m,0}$            | 563013          | N                        | $P_{m,0} = \sigma_{pm,0} * A_p$                       |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| Determination of the required amount of reinforcing steel                                                                                                |                      |                 |                          |                                                       |
| Bending moment due to permanent and variable load                                                                                                        | $M_{g+q}$            | 5               | kNm                      | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$                   |
| Bending moment due to prestressing                                                                                                                       | $M_p$                | 0               | Nmm                      | $M_p = \gamma_P * P_{m,\infty} * e_p$                 |
|                                                                                                                                                          |                      | 0               | kNm                      |                                                       |
| Total bending moment                                                                                                                                     | $M_{tot}$            | 5               | kNm                      | $M_{tot} = M_{g+q} - M_p$                             |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| <i>Time dependent losses are estimated to be</i>                                                                                                         | 10%                  |                 | (Walraven & Braam, 2019) |                                                       |
| <i>Friction loss is assumed to be</i>                                                                                                                    | 10%                  |                 | (Walraven & Braam, 2019) |                                                       |
| Working prestressing steel stress                                                                                                                        | $\sigma_{pm,\infty}$ | 1075            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$      |
|                                                                                                                                                          |                      |                 |                          |                                                       |
| <i>It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit (<math>f_{p0,1k}</math>)</i>                    |                      |                 |                          |                                                       |
|                                                                                                                                                          | $\Delta\sigma$       | 518             | N/mm <sup>2</sup>        | $f_{p0,1k} - \sigma_{pm,\infty}$                      |
|                                                                                                                                                          |                      |                 |                          |                                                       |

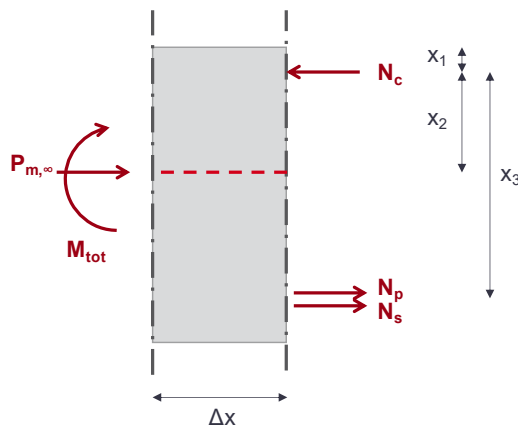


Figure K.38: Total bending moment around the resulting concrete compressive

|                                                              |                                                                     |         |                    |                                                                                                                              |
|--------------------------------------------------------------|---------------------------------------------------------------------|---------|--------------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                              | x <sub>1</sub>                                                      | 9       | mm                 |                                                                                                                              |
|                                                              | x <sub>2</sub>                                                      | 30      | mm                 |                                                                                                                              |
|                                                              | x <sub>3</sub>                                                      | 30      | mm                 | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                           | N <sub>p</sub>                                                      | 219575  | N                  | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force                                   | P <sub>m,∞</sub>                                                    | 456040  | N                  | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                          | N <sub>s</sub>                                                      | -675615 | N                  | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Required reinforcement area                                  | A <sub>sl,req</sub>                                                 | -1351   | mm <sup>2</sup>    | $N_s = f_{yk} * A_{sl}$                                                                                                      |
|                                                              | A <sub>sl</sub> < 0 mm <sup>2</sup> : minimum reinforcement applies |         |                    |                                                                                                                              |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Detailing of reinforcement                                   |                                                                     |         |                    |                                                                                                                              |
| Minimum reinforcement is required                            |                                                                     |         |                    |                                                                                                                              |
|                                                              | α <sub>e</sub>                                                      | 7       |                    | (Walraven & Braam, 2019)                                                                                                     |
| Minimum reinforcement ratio                                  | ρ <sub>min</sub>                                                    | 0,6997% |                    | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$                                                                   |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Smallest width of the cross-section in the tensile area      | b <sub>w</sub>                                                      | 100     | mm                 |                                                                                                                              |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Applied reinforcement ratio                                  | ρ                                                                   | 0,752%  | ≤ ρ <sub>min</sub> | $\rho_l = \frac{A_{sl}}{b_w d}$                                                                                              |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Control of the crack width (SLS)                             |                                                                     |         |                    |                                                                                                                              |
| Maximum crack width                                          | w <sub>max</sub>                                                    | 30      | mm                 | EN 1992-1-1/NB                                                                                                               |
|                                                              |                                                                     |         |                    |                                                                                                                              |
| Ratio of bond strength of prestressing and reinforcing steel | ξ                                                                   | 0,70    |                    | EN 1992-1-1                                                                                                                  |
| Bonding factor of prestressing steel                         | ξ <sub>1</sub>                                                      | 0,84    |                    | $\xi_1 = \sqrt{\xi * \frac{\varphi_s}{\varphi_p}}$                                                                           |
|                                                              |                                                                     |         |                    |                                                                                                                              |

|                                                   |                 |          |                   |                                                                                                                                                                                                                      |
|---------------------------------------------------|-----------------|----------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bending moment due to permanent and variable load | $M_{g+q}$       | 16       | kNm               | $M_{g+q} = \frac{1}{8} q_{SL} l^2$                                                                                                                                                                                   |
| Bending moment due to prestressing                | $M_p$           | 0        | Nmm               | $M_p = P_{m,\infty} * e_p$                                                                                                                                                                                           |
|                                                   |                 | 0        | kNm               |                                                                                                                                                                                                                      |
| Total bending moment                              | $M_{tot}$       | 16       | kNm               | $M_{tot} = M_{g+q} - M_p$                                                                                                                                                                                            |
|                                                   |                 |          |                   |                                                                                                                                                                                                                      |
| Strain in steel                                   | $\varepsilon_s$ | 0,000733 |                   | $\sum M = 0$ $\Leftrightarrow \varepsilon_s (A_s + \xi_1 A_p) E_s * x_3 + P_{m,\infty} * x_2 = M_{tot}$ $\Leftrightarrow \varepsilon_s = \frac{M_{tot} - P_{m,\infty} * x_2}{(A_s + \xi_1 A_p) E_s * x_3}$           |
| The cross-section is cracked in SLS               |                 |          |                   |                                                                                                                                                                                                                      |
|                                                   |                 |          |                   |                                                                                                                                                                                                                      |
| Stress in steel                                   | $\sigma_s$      | 147      | N/mm <sup>2</sup> | $\sigma_s = E_s * \varepsilon_s$                                                                                                                                                                                     |
|                                                   |                 |          |                   |                                                                                                                                                                                                                      |
| Strain in concrete                                | $\varepsilon_c$ | 0,000489 |                   | $\sum H = 0$ $\Leftrightarrow \varepsilon_s (A_s + \xi_1 A_p) E_s + P_{m,\infty} = \varepsilon_c A_{cf} E_c$ $\Leftrightarrow \varepsilon_s = \frac{\varepsilon_s (A_s + \xi_1 A_p) E_s + P_{m,\infty}}{A_{cf} E_c}$ |
|                                                   |                 |          |                   |                                                                                                                                                                                                                      |
| Tension zone height                               | $t$             | 18       | mm                | $t = \frac{\varepsilon_s}{\varepsilon_s + \varepsilon_c} * x_3$                                                                                                                                                      |
| Height of the effective tensile zone              | $a_e$           | 18       | mm                |                                                                                                                                                                                                                      |
|                                                   | $a_e/t$         | 1,00     |                   |                                                                                                                                                                                                                      |
|                                                   |                 |          |                   |                                                                                                                                                                                                                      |

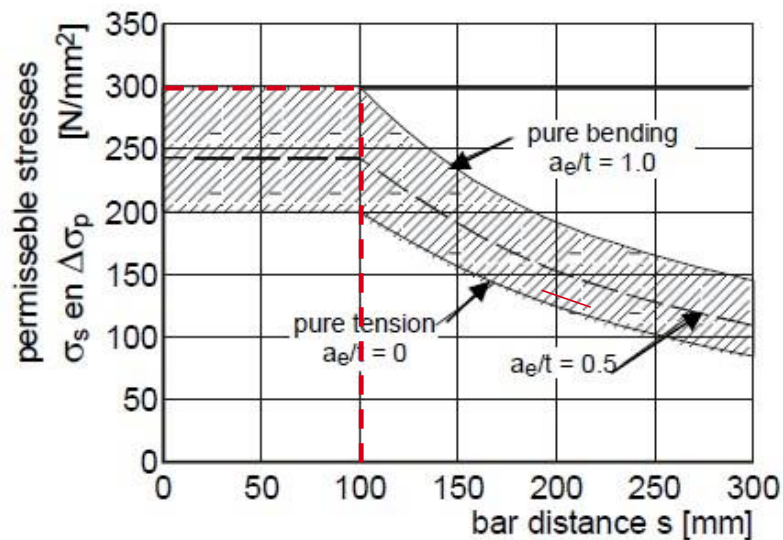


Figure K.39: Allowed maximum stress in the reinforcement as a function of the bar spacing  $s$  (Walraven & Braam, 2019)

|                    |                  |                   |                   |                       |
|--------------------|------------------|-------------------|-------------------|-----------------------|
| Bar spacing        | $S_p$            | 61                | mm                |                       |
| Permissible stress | $\sigma_{s,max}$ | 300               | N/mm <sup>2</sup> |                       |
|                    |                  |                   |                   |                       |
| Check              | 147              | N/mm <sup>2</sup> | ≤                 | 300 N/mm <sup>2</sup> |

## K.4 Option B.i: Short span with accessibility from the bottom

### K.4.1 Input

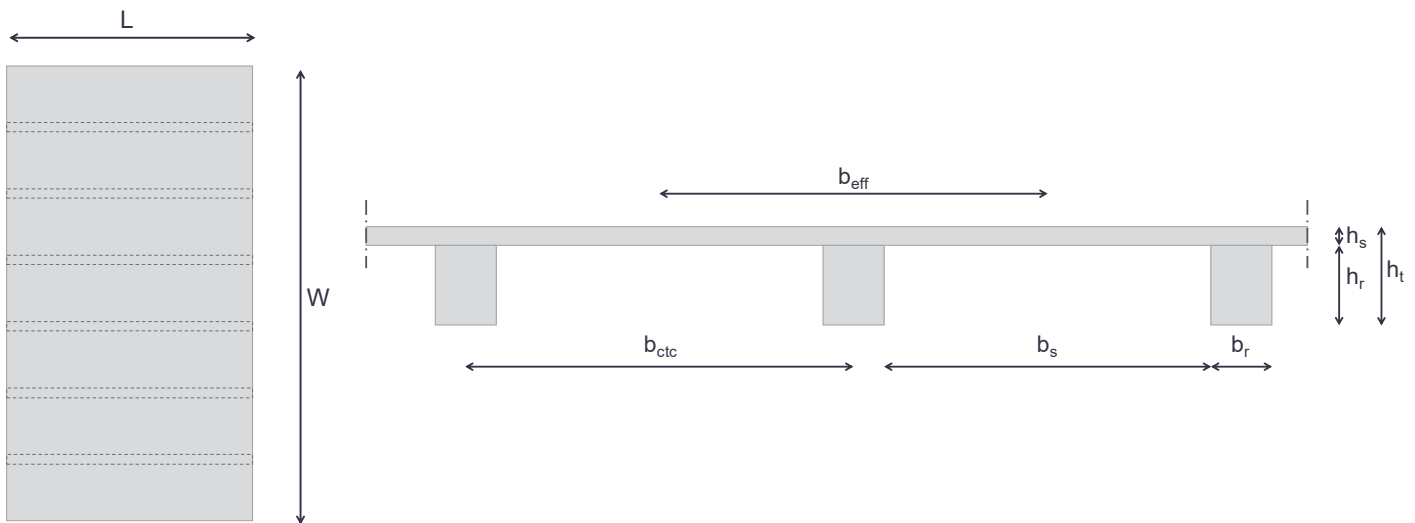


Figure K.40: Indication of the dimensions

| Dimensions                             |              |      |                   |                                                              |
|----------------------------------------|--------------|------|-------------------|--------------------------------------------------------------|
| Span                                   | L            | 3300 | mm                |                                                              |
| Width                                  | W            | 6100 | mm                |                                                              |
| Number of ribs                         | n            | 7    |                   |                                                              |
| Height slab                            | $h_s$        | 34   | mm                | $\geq \max[\varphi_{t,t}; \varphi_{t,b}] + 2 * c_{nom} = 34$ |
| Height rib                             | $h_r$        | 170  | mm                | $\geq 170$ mm                                                |
| Total height                           | $h_t$        | 204  | mm                | $h_t = h_s + h_r$                                            |
| Width rib                              | $b_r$        | 100  | mm                |                                                              |
| Space between ribs                     | $b_s$        | 771  | mm                | $\geq 170$ mm                                                |
| Centre to centre distance between ribs | $b_{ctc}$    | 871  | mm                | $b_{ctc} = b_r + b_s$                                        |
| Concrete properties                    |              |      |                   |                                                              |
| <u>C30/37</u>                          |              |      |                   |                                                              |
| Density                                | $\rho_{rep}$ | 25   | kN/m <sup>3</sup> |                                                              |
| Characteristic cylinder strength       | $f_{ck}$     | 30   | N/mm <sup>2</sup> |                                                              |
| Partial safety factor concrete         | $\gamma_c$   | 1,5  |                   |                                                              |
| Design compressive strength            | $f_{cd}$     | 20   | N/mm <sup>2</sup> |                                                              |
| Design tensile strength                | $f_{ctd}$    | 1,35 | N/mm <sup>2</sup> |                                                              |
| Mean tensile strength                  | $f_{ctm}$    | 2,9  | N/mm <sup>2</sup> |                                                              |
| Reinforcement properties               |              |      |                   |                                                              |
| Longitudinal reinforcement             |              |      |                   |                                                              |
| Diameter longitudinal reinforcement    | $\varphi_l$  | 8    | mm                |                                                              |



|                                                    |                  |      |                   |                                                         |
|----------------------------------------------------|------------------|------|-------------------|---------------------------------------------------------|
| Number of longitudinal reinforcement bars          | n                | 3    |                   |                                                         |
| Surface area longitudinal reinforcement            | $A_{sl}$         | 151  | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$              |
| Spacing of longitudinal reinforcement              | $s_l$            | 33   | mm                | $s_l = \frac{b_{eff}}{n}$                               |
| Effective height of the cross-section              | $d_l$            | 185  | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$         |
| <b>Transversal reinforcement top</b>               |                  |      |                   |                                                         |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars top       | n                | 10   |                   |                                                         |
| Surface area transversal reinforcement bars top    | $A_{st,t}$       | 126  | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$        |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$        | 100  | mm                | $s_{t,t} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 17   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
| <b>Transversal reinforcement bottom</b>            |                  |      |                   |                                                         |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars bottom    | n                | 10   |                   |                                                         |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$       | 126  | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$        |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$        | 100  | mm                | $s_{t,b} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 17   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
| <b>Concrete cover</b>                              |                  |      |                   |                                                         |
| Minimum cover due to environmental conditions      | $c_{min,dur}$    | 10   | mm                | XC1                                                     |
| Minimum cover due to bond requirement              | $c_{min,b}$      | 8    | mm                | EN 1992-1-1                                             |
| Minimum cover                                      | $c_{min}$        | 10   | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10\text{mm}\}$ |
| Allowance in design for deviation                  | $\Delta c_{dev}$ | 5    | mm                | EN 1992-1-1/NB                                          |
| Nominal cover                                      | $c_{nom}$        | 15   | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$                    |
| <b>Reinforcement steel</b>                         |                  |      |                   |                                                         |
| B500 B                                             |                  |      |                   |                                                         |
| Yield strength                                     | $f_{yk}$         | 500  | N/mm <sup>2</sup> |                                                         |
| Partial safety factor steel                        | $\gamma_s$       | 1,15 |                   |                                                         |
| Design yield stress                                | $f_{yd}$         | 435  | N/mm <sup>2</sup> |                                                         |

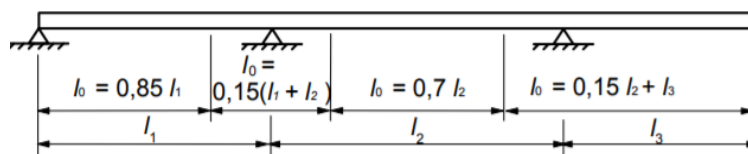


Figure K.41: Definition of  $l_0$ , for calculation of effective flange width from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

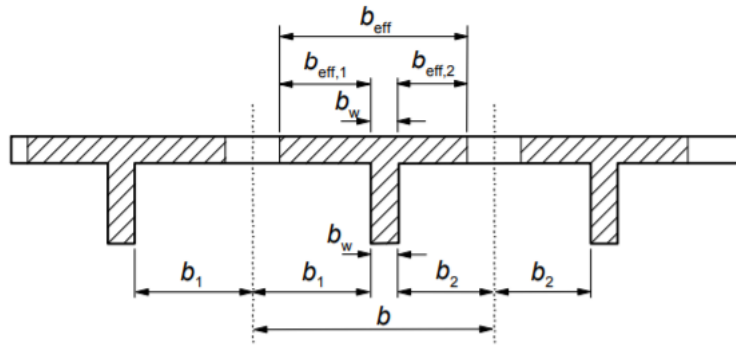


Figure K.42: Effective flange width parameters from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |      |    |                                           |
|------------------------|------|----|-------------------------------------------|
| $l_1$                  | 3300 | mm | $l_1 = L$                                 |
| $l_0$                  | 1650 | mm | $l_0 = 0,85l_1$                           |
| $b_1$                  | 386  | mm | $b_1 = 0.5 * b_s$                         |
| $b_2$                  | 386  | mm | $b_2 = 0.5 * b_s$                         |
| $b_w$                  | 100  | mm | $b_w = b_r$                               |
| $b$                    | 871  | mm | $b = b_{ctc}$                             |
| $b_{eff,1}$            | 330  | mm | $b_{eff,1} = 0.2b_1 + 0.1l_0 \leq 0.2l_0$ |
| $b_{eff,2}$            | 165  | mm | $b_{eff,2} = 0.2b_2 + 0.1l_0 \leq 0.2l_0$ |
| $b_{eff}$              | 595  | mm | $b_{eff} = \sum b_{eff,i} + b_w \leq b$   |

#### K.4.2 Loads

| Permanent loads                                     |                |      |                   |                                                                                                 |
|-----------------------------------------------------|----------------|------|-------------------|-------------------------------------------------------------------------------------------------|
| Slab                                                | $g_{slab}$     | 0,85 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                                                   |
| Rib                                                 | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                                    |
| Top floor panels                                    | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                                                 |
| Building services                                   | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                                            |
| Total deadload longitudinal direction               | $g_{k,l}$      | 1,60 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                     |
| Total deadload transversal direction                | $g_{k,t}$      | 1,84 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1 m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1 m]$ |
| Variable load                                       |                |      |                   |                                                                                                 |
| Variable floor load residential buildings           | $q_{res}$      | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                                                  |
| Movable partitions                                  | $q_{part}$     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                                     |
| Total variable floor load                           | $q_{tot}$      | 2,55 | kN/m <sup>2</sup> |                                                                                                 |
| Total variable floor load in longitudinal direction | $q_{k,l}$      | 2,22 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                                                   |

|                                                    |              |      |      |                                    |
|----------------------------------------------------|--------------|------|------|------------------------------------|
| Total variable floor load in transversal direction | $q_{k,t}$    | 2,55 | kN/m | $q_{k,t} = q_{tot} * [1\text{ m}]$ |
| <b>Load combination ULS</b>                        |              |      |      |                                    |
| Partial factor for permanent loads                 | $\gamma_G$   | 1,35 |      | EN 1990/NB                         |
| Partial factor for variable loads                  | $\gamma_Q$   | 1,5  |      | EN 1990/NB                         |
| ULS load combination in longitudinal direction     | $q_{ULS,l}$  | 5,50 | kN/m | EN 1990 6.10a                      |
| ULS load combination in transversal direction      | $q_{ULS,t}$  | 6,31 | kN/m | EN 1990 6.10a                      |
| <b>Load combination SLS</b>                        |              |      |      |                                    |
| Factor for frequent value of a variable action     | $\psi_{1,1}$ | 0,5  |      | EN 1990                            |
| SLS load combination in longitudinal direction     | $q_{SLS,l}$  | 2,71 | kN/m | EN 1990 6.15a                      |
| SLS load combination in transversal direction      | $q_{SLS,t}$  | 3,11 | kN/m | EN 1990 6.15a                      |

#### K.4.3 Ultimate limit state – Longitudinal direction

##### Load distribution

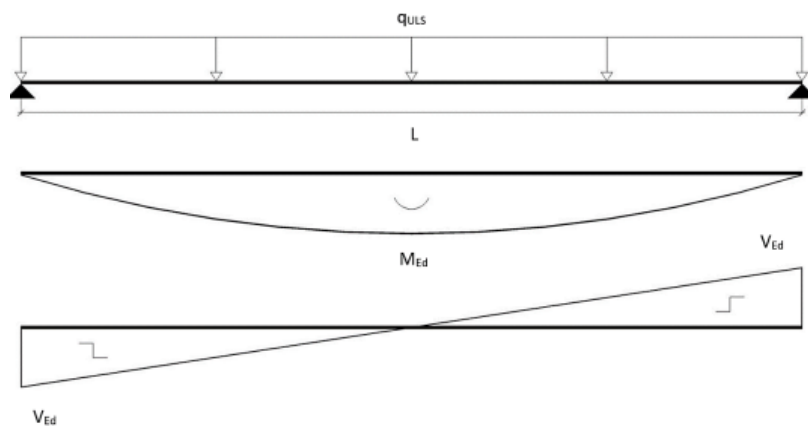


Figure K.43: Load distribution in the longitudinal direction

|                               |          |      |     |                                      |
|-------------------------------|----------|------|-----|--------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 7,48 | kNm | $M_{Ed} = \frac{1}{8} q_{ULS,l} l^2$ |
| Maximum acting shear force    | $V_{Ed}$ | 9,07 | kN  | $V_{Ed} = \frac{1}{2} q_{ULS,l} l$   |
|                               |          |      |     |                                      |

##### Bending moment reinforcement

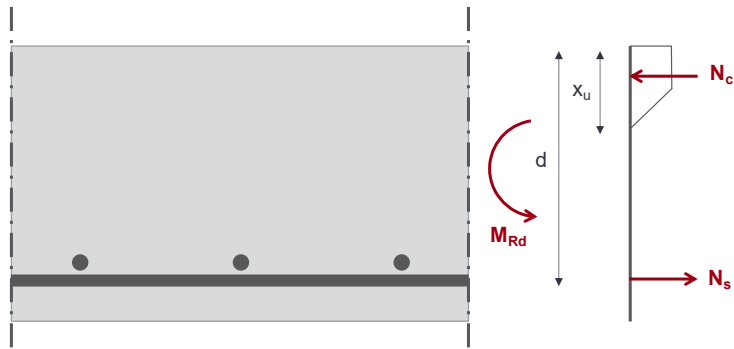


Figure K.44: Concrete cross-section

|                                                         |            |          |                   |                                                                                                          |
|---------------------------------------------------------|------------|----------|-------------------|----------------------------------------------------------------------------------------------------------|
| Rebar tensile force                                     | $N_s$      | 65564    | N                 | $N_s = A_{sl} * f_{yd}$                                                                                  |
| Concrete compressive force                              | $N_c$      |          | N                 | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                                             |
| Concrete compressive zone height                        | $x_u$      | 7,35     | mm                | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$                             |
|                                                         |            |          |                   |                                                                                                          |
| Bending moment resistance                               | $M_{Rd}$   | 11941442 | Nmm               | $M_{Rd} = N_s * (d - 0.39x_u)$                                                                           |
|                                                         |            | 11,94    | kNm               |                                                                                                          |
|                                                         |            |          |                   |                                                                                                          |
| Unity Check                                             | 0,63       | ≤        | 1,0               |                                                                                                          |
|                                                         |            |          |                   |                                                                                                          |
| <b>Shear reinforcement</b>                              |            |          |                   |                                                                                                          |
| <b>Minimal reinforcement</b>                            |            |          |                   |                                                                                                          |
|                                                         | $k$        | 2,0      |                   | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                                  |
| Smallest width of the cross-section in the tensile area | $b_w$      | 100      | mm                |                                                                                                          |
| Reinforcement ratio for longitudinal reinforcement      | $\rho_l$   | 0,02     |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                                |
|                                                         | $C_{Rd,c}$ | 0,12     |                   | EN 1992-1-1/NB                                                                                           |
|                                                         | $v_{min}$  | 0,30     | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                               |
|                                                         |            |          |                   |                                                                                                          |
|                                                         | $V_{Rd,c}$ | 17382    | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w$<br>$* d \leq v_{min} * b_w * d)$ |
|                                                         |            | 17       | kN                |                                                                                                          |
|                                                         |            |          |                   |                                                                                                          |
| Unity Check                                             | 0,52       | ≤        | 1,0               |                                                                                                          |

#### K.4.4 Ultimate limit state – Transversal direction

##### Load distribution

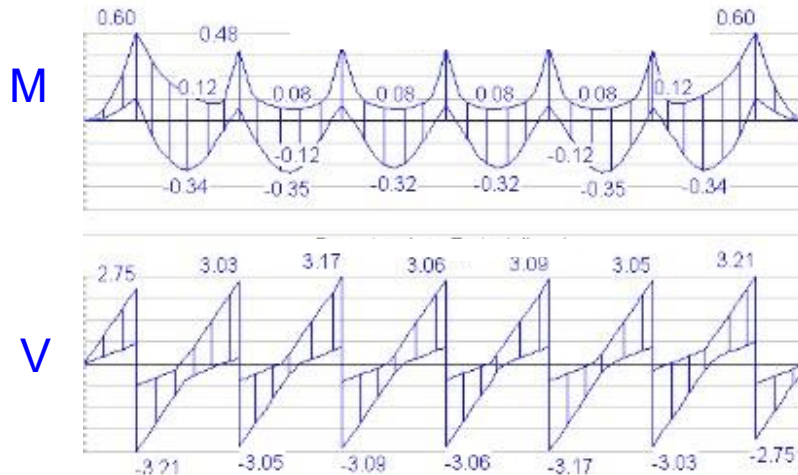


Figure K.45: Load distribution in transversal direction (enveloping fundamental combination using Technosoft Liggers)

|                                         |                 |      |     |  |
|-----------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment at top    | $M_{Ed,top}$    | 0,6  | kNm |  |
| Maximum acting bending moment at bottom | $M_{Ed,bottom}$ | 0,35 | kNm |  |
| Maximum acting shear force              | $V_{Ed}$        | 3,21 | kN  |  |

##### Bending moment reinforcement

##### Bending moment reinforcement at the top

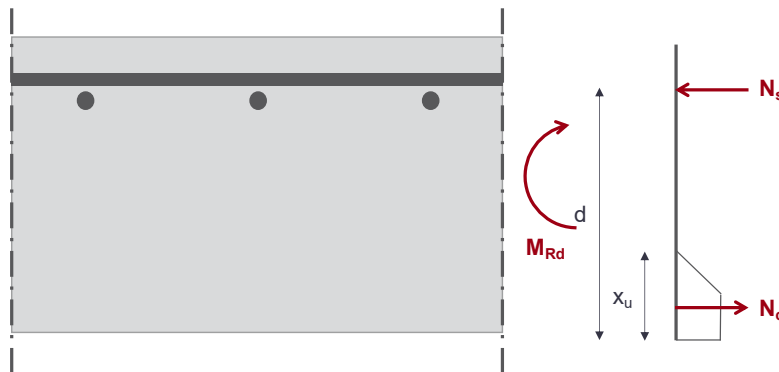


Figure K.46: Concrete cross-section top reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 54636  | N   | $N_s = A_{st,t} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,64   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 851205 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,85   | kNm |                                                                                   |
| Unity Check                      | 0,70     | ≤      | 1,0 |                                                                                   |

### Bending moment reinforcement at the bottom

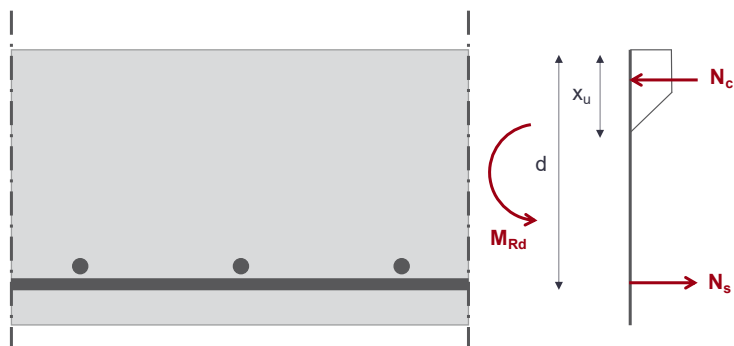


Figure K.47: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 54636  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,64   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 851205 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,85   | kNm |                                                                                   |
| Unity Check                      |          | 0,41   | ≤   | 1                                                                                 |
| Shear in web-flange interface    |          |        |     |                                                                                   |

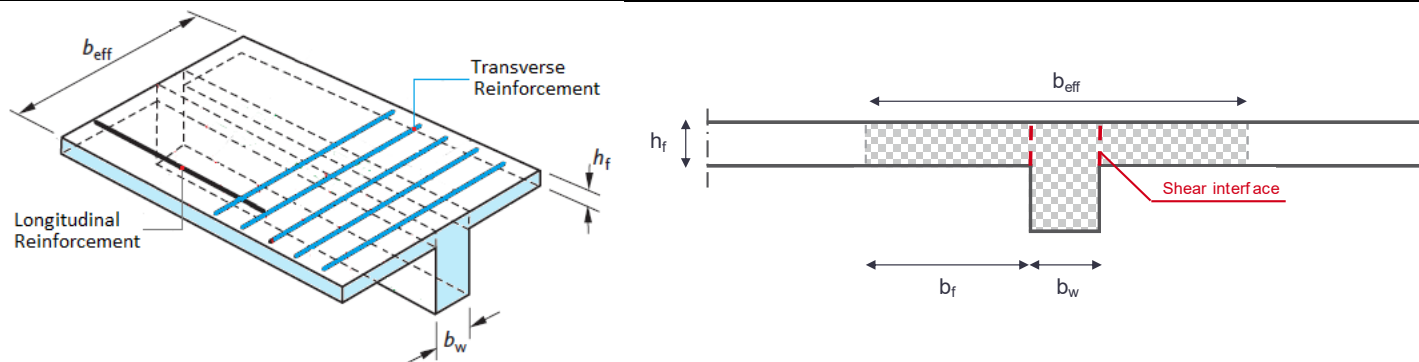


Figure K.48: Parameters for shear in the web-flange interface (Walraven, 2011)

|                 |          |       |                   |                                                                           |
|-----------------|----------|-------|-------------------|---------------------------------------------------------------------------|
| Width of flange | $b_f$    | 247,5 | mm                |                                                                           |
| Shear stress    | $v_{Ed}$ | 0,24  | N/mm <sup>2</sup> | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$                |
|                 | $k$      | 0,4   |                   | EN 1992-1-1/NB                                                            |
| Check           |          | 0,24  | ≤                 | 0,54<br>$v_{ed} \leq k * f_{ctd}$<br>No transverse reinforcement required |

#### K.4.5 Serviceability limit state

| Reinforcement for crack control                                                                                          |                |       |                   |                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------|----------------|-------|-------------------|--------------------------------------------------------------------------------------|
| Minimum areas of reinforcement                                                                                           |                |       |                   |                                                                                      |
| Absolute value of the maximum stress permitted in the reinforcement immediately after the formation of the crack         | $\sigma_s$     | 500   | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which takes account of the stress distribution within the section immediately prior to cracking              | $k_c$          | 0,4   |                   | EN 1992-1-1                                                                          |
| Mean value of the tensile strength of the concrete effective at the times when the cracks may first be expected to occur | $f_{ct,eff}$   | 2,9   | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which allows for the effect of non-uniform self-equilibrating                                                |                |       |                   |                                                                                      |
| Slab                                                                                                                     | k              | 1,19  |                   | EN 1992-1-1                                                                          |
| Rib                                                                                                                      | k              | 1,00  |                   | EN 1992-1-1                                                                          |
| Area or concrete within the tensile zone                                                                                 |                |       |                   |                                                                                      |
| Rib (longitudinal direction)                                                                                             | $A_{ct,r}$     | 8500  | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the top (transversal direction)                                                               | $A_{ct,t,t}$   | 17000 | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the bottom (transversal direction)                                                            | $A_{ct,t,b}$   | 17000 | mm <sup>2</sup>   |                                                                                      |
| Minimum area of reinforcement                                                                                            |                |       |                   |                                                                                      |
| Rib in longitudinal direction                                                                                            | $A_{smin,l,r}$ | 20    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab in transversal direction, top                                                                                       | $A_{smin,t,t}$ | 47    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab in transversal direction, bottom                                                                                    | $A_{smin,t,b}$ | 47    | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| <i>The minimum areas or reinforcement are included in the reinforcement requirements in Appendix K.4.6</i>               |                |       |                   |                                                                                      |
| Restrictions for bar diameters and spacing                                                                               |                |       |                   |                                                                                      |
| Limit value crack width                                                                                                  | $w_{max}$      | 0,4   | mm                | EN 1992-1-1/NB                                                                       |
| Longitudinal direction                                                                                                   |                |       |                   |                                                                                      |
| Bending moment in SLS                                                                                                    | $M_{Efreq}$    | 3,69  | kNm               | $M_{Ed} = \frac{1}{8} q_{SLS,l} l^2$                                                 |
| Bending moment resistance                                                                                                | $M_{Rd}$       | 11,94 | kNm               |                                                                                      |
| Steel stress                                                                                                             | $\sigma_s$     | 134   | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
| Maximum bar size                                                                                                         | $\varphi'_s$   | 45    | mm                | EN 1992-1-1                                                                          |
| Adapted maximum bar size, top                                                                                            | $\varphi_s$    | 39    | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
| Check $\varphi_s > \varphi_l$                                                                                            | 39             | mm    | >                 | 8 mm                                                                                 |
| Transversal direction                                                                                                    |                |       |                   |                                                                                      |



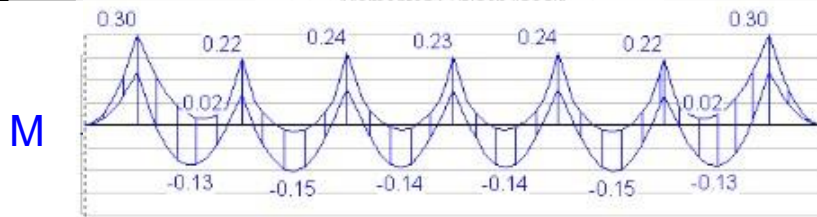


Figure K.49: Load distribution in transversal direction (frequent combination using Technosoft Liggers)

|                                           |              |          |                   |                                                                                                                                                                                 |
|-------------------------------------------|--------------|----------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bending moment SLS, top                   | $M_{Efreq}$  | 0,3      | kNm               |                                                                                                                                                                                 |
| Bending moment SLS, bottom                | $M_{Efreq}$  | 0,15     | kNm               |                                                                                                                                                                                 |
| Bending moment resistance, top            | $M_{Rd}$     | 0,85     | kNm               |                                                                                                                                                                                 |
| Bending moment resistance, bottom         | $M_{Rd}$     | 0,85     | kNm               |                                                                                                                                                                                 |
| Steel stress, top                         | $\sigma_s$   | 153      | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                  |
| Steel stress, bottom                      | $\sigma_s$   | 77       | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                  |
| Maximum bar size, top                     | $\varphi'_s$ | 41       | mm                | EN 1992-1-1                                                                                                                                                                     |
| Maximum bar size, bottom                  | $\varphi'_s$ | 57       | mm                | EN 1992-1-1                                                                                                                                                                     |
| Adapted maximum bar size, top             | $\varphi_s$  | 8        | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                            |
| Adapted maximum bar size, bottom          | $\varphi_s$  | 11       | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                            |
| Check $\varphi_s > \varphi_{t,t}$         |              | 8        | mm                | > 4 mm                                                                                                                                                                          |
| Check $\varphi_s > \varphi_{t,b}$         |              | 11       | mm                | > 4 mm                                                                                                                                                                          |
| <b>Slenderness for deflection control</b> |              |          |                   |                                                                                                                                                                                 |
| <b>Longitudinal direction</b>             |              |          |                   |                                                                                                                                                                                 |
| Reference reinforcement ratio             | $\rho_0$     | 0,005477 |                   | $\rho_0 = 10^{-3} * \sqrt{f_{ck}}$                                                                                                                                              |
| Tension reinforcement ratio               | $\rho_l$     | 0,00405  |                   | $\rho_l = \frac{A_{sl}}{A}$                                                                                                                                                     |
| Factor for different structural systems   | K            | 1        |                   | EN 1992-1-1                                                                                                                                                                     |
| Compression reinforcement ratio           | $\rho'_l$    | 0        |                   |                                                                                                                                                                                 |
| Limit span/depth                          | $l/d$        | 26       |                   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_l} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_l} - 1 \right)^{3/2} \right] \text{ if } \rho_l \leq \rho_0$ |
| Corrective value for slenderness          |              | 2,31     |                   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Check                                     | $l/h$        | 16       | <                 | 59                                                                                                                                                                              |

|                                          |              |          |   |                                                                                                                                                                               |
|------------------------------------------|--------------|----------|---|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          |              |          |   |                                                                                                                                                                               |
| <b>Transversal direction</b>             |              |          |   |                                                                                                                                                                               |
| Tension reinforcement ratio top          | $\rho_{t,t}$ | 0,003696 |   | $\rho_{t,t} = \frac{A_{st,t}}{A}$                                                                                                                                             |
| Tension reinforcement ratio bottom       | $\rho_{t,b}$ | 0,003696 |   | $\rho_{t,b} = \frac{A_{st,b}}{A}$                                                                                                                                             |
|                                          |              |          |   |                                                                                                                                                                               |
| Factor for different structural systems  | K            | 1,5      |   | EN 1992-1-1                                                                                                                                                                   |
| Compression reinforcement ratio          | $\rho'_l$    | 0        |   |                                                                                                                                                                               |
|                                          |              |          |   |                                                                                                                                                                               |
| Limit span/depth, top                    | $l/d$        | 44       |   | $\frac{l}{d} = K \left[ 11 + 1.5\sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2\sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
| Limit span/depth, bottom                 | $l/d$        | 44       |   | $\frac{l}{d} = K \left[ 11 + 1.5\sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2\sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
|                                          |              |          |   |                                                                                                                                                                               |
| Corrective value for slenderness, top    |              | 2,02     |   |                                                                                                                                                                               |
| Corrective value for slenderness, bottom |              | 4,05     |   |                                                                                                                                                                               |
|                                          |              |          |   |                                                                                                                                                                               |
| Check, top                               | $l/h$        | 26       | < | 88                                                                                                                                                                            |
| Check, bottom                            | $l/h$        | 26       | < | 176                                                                                                                                                                           |

#### K.4.6 Detailing reinforcement requirements

|                                                   |               |         |                 |                                                      |
|---------------------------------------------------|---------------|---------|-----------------|------------------------------------------------------|
| <b>Minimum longitudinal tension reinforcement</b> |               |         |                 |                                                      |
| Section Modulus                                   | W             | 989832  | mm <sup>3</sup> |                                                      |
| Minimum principal reinforcement area (1)          | $A_{s,min,1}$ | 1099263 | mm <sup>2</sup> | $A_{s,min,1} = \frac{f_{ctm} * W}{f_{yd} * 0.9 * d}$ |
| Required reinforcement area for ULS               | $A_s$         | 103     | mm <sup>2</sup> | $A_s = \frac{M_{Ed}}{f_{yd} * 0.9 * d}$              |
| Minimum principal reinforcement area (2)          | $A_{s,min,2}$ | 129     | mm <sup>2</sup> | $A_{s,min,2} = 1.25 A_s$                             |
| Minimum principal reinforcement area              | $A_{s,min}$   | 129     | mm <sup>2</sup> | $A_{s,min} = \min[A_{s,min,1}; A_{s,min,2}]$         |
|                                                   |               |         |                 |                                                      |
| <b>Maximum reinforcement area</b>                 |               |         |                 |                                                      |
| <b>Longitudinal direction</b>                     |               |         |                 |                                                      |
| Cross-sectional area of concrete                  | $A_c$         | 37230   | mm <sup>2</sup> | $A_c = b_{eff} * h_s + b_r * h_r$                    |
| Maximum reinforcement area                        | $A_{s,max}$   | 1489,2  | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |
|                                                   |               |         |                 |                                                      |
| <b>Transversal direction</b>                      |               |         |                 |                                                      |
| Cross-sectional area of concrete                  | $A_c$         | 34000   | mm <sup>2</sup> | $A_c = h_s * [1 m]$                                  |
| Maximum reinforcement area                        | $A_{s,max}$   | 1360    | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |
|                                                   |               |         |                 |                                                      |

| Minimum reinforcement spacing                                       |                            |                 |    |                                                       |                 |   |      |                 |
|---------------------------------------------------------------------|----------------------------|-----------------|----|-------------------------------------------------------|-----------------|---|------|-----------------|
|                                                                     | k <sub>1</sub>             | 1               |    | EN 1992-1-1/NB                                        |                 |   |      |                 |
| Minimum reinforcement spacing (1) longitudinal reinforcement        | S <sub>min,1,l</sub>       | 8               | mm | $s_{min,1} = k_1 * \varphi_l$                         |                 |   |      |                 |
| Minimum reinforcement spacing (1) transversal reinforcement, top    | S <sub>min,1,t,t</sub>     | 4               | mm | $s_{min,1} = k_1 * \varphi_{t,t}$                     |                 |   |      |                 |
| Minimum reinforcement spacing (1) transversal reinforcement, bottom | S <sub>min,1,t,b</sub>     | 4               | mm | $s_{min,1} = k_1 * \varphi_{t,b}$                     |                 |   |      |                 |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Maximum size of aggregate                                           | d <sub>g</sub>             | 16              | mm | Assumption                                            |                 |   |      |                 |
|                                                                     | k <sub>2</sub>             | 5               |    | EN 1992-1-1/NB                                        |                 |   |      |                 |
| Minimum reinforcement spacing (2)                                   | S <sub>min,2</sub>         | 21              | mm | $s_{min,2} = d_g + k_2$                               |                 |   |      |                 |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Minimum reinforcement spacing longitudinal reinforcement            | S <sub>min,l</sub>         | 21              | mm | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |                 |   |      |                 |
| Minimum reinforcement spacing transversal reinforcement, top        | S <sub>min,t,t</sub>       | 21              | mm | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |                 |   |      |                 |
| Minimum reinforcement spacing transversal reinforcement, bottom     | S <sub>min,t,b</sub>       | 21              | mm | $s_{min} = \max[s_{min,1}; s_{min,2}; 20 \text{ mm}]$ |                 |   |      |                 |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Maximum reinforcement spacing                                       |                            |                 |    |                                                       |                 |   |      |                 |
| Maximum reinforcement spacing for principal reinforcement           | S <sub>max,principal</sub> | 250             | mm | $s_{max,principal} = 2 * h_t \leq 250 \text{ mm}$     |                 |   |      |                 |
| Maximum reinforcement spacing for secondary reinforcement           | S <sub>max,secondary</sub> | 102             | mm | $s_{max,secondary} = 3 * h_s \leq 400 \text{ mm}$     |                 |   |      |                 |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Check                                                               |                            |                 |    |                                                       |                 |   |      |                 |
| Longitudinal reinforcement                                          |                            |                 |    |                                                       |                 |   |      |                 |
| Area of rebar                                                       | 129                        | mm <sup>2</sup> | <  | 151                                                   | mm <sup>2</sup> | < | 1489 | mm <sup>2</sup> |
| Spacing of rebar                                                    | 21                         | mm              | <  | 33                                                    | mm              | < | 250  | mm              |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Transversal reinforcement                                           |                            |                 |    |                                                       |                 |   |      |                 |
| Area of rebar top                                                   | 47                         | mm <sup>2</sup> | <  | 126                                                   | mm <sup>2</sup> | < | 1360 | mm <sup>2</sup> |
| Spacing of rebar top                                                | 21                         | mm              | <  | 100                                                   | mm              | < | 102  | mm              |
|                                                                     |                            |                 |    |                                                       |                 |   |      |                 |
| Area of rebar bottom                                                | 47                         | mm <sup>2</sup> | <  | 126                                                   | mm <sup>2</sup> | < | 1360 | mm <sup>2</sup> |
| Spacing of rebar bottom                                             | 21                         | mm              | <  | 100                                                   | mm              | < | 102  | mm              |

#### K.4.7 Rib openings

| Input                                     |             |      |    |                                 |
|-------------------------------------------|-------------|------|----|---------------------------------|
| Height slab                               | $h_s$       | 34   | mm |                                 |
| Height rib                                | $h_r$       | 22,5 | mm | $h_{r,o} = \frac{h_r - 125}{2}$ |
| Total height                              | $h_t$       | 56,5 | mm | $h_t = h_s + h_{r,o}$           |
|                                           |             |      |    |                                 |
| Nominal cover                             | $c_{nom}$   | 15   | mm |                                 |
|                                           |             |      |    |                                 |
| Diameter longitudinal reinforcement       | $\varphi_l$ | 8    | mm |                                 |
| Number of longitudinal reinforcement bars | $n$         | 3    |    |                                 |

|                                         |          |       |                 |                                           |
|-----------------------------------------|----------|-------|-----------------|-------------------------------------------|
| Surface area longitudinal reinforcement | $A_{sl}$ | 151   | mm <sup>2</sup> | $A_{sl} = n * \frac{1}{4} \pi \phi_l^2$   |
| Spacing of longitudinal reinforcement   | $s_l$    | 33    | mm              | $s_l = \frac{b_r}{n}$                     |
| Diameter stirrups                       | $\phi_s$ | 6     | mm              |                                           |
| Surface area stirrups                   | $A_{sw}$ | 28,27 | mm <sup>2</sup> | $A_{sw} = n * \frac{1}{4} \pi \phi_s^2$   |
| Effective height of the cross-section   | $d_l$    | 31,5  | mm              | $d = h - c - \phi_s - \frac{1}{2} \phi_l$ |
|                                         |          |       |                 |                                           |

### Load distribution

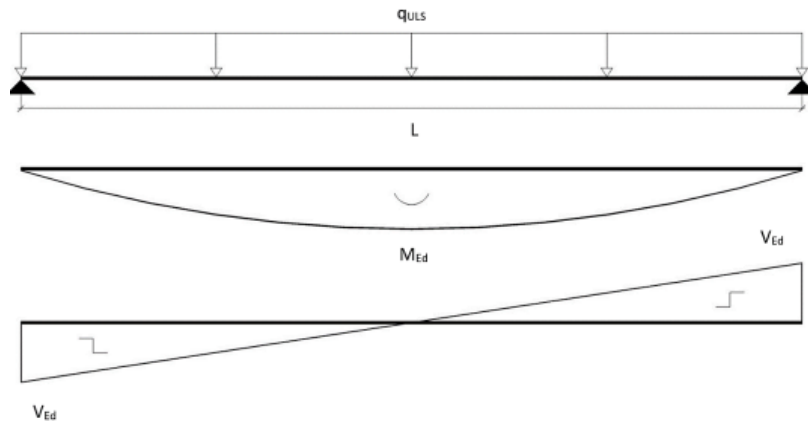


Figure K.50: Load distribution in the longitudinal direction

|                               |          |      |     |                                             |
|-------------------------------|----------|------|-----|---------------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 1,87 | kNm | See unity check longitudinal bending moment |
| Maximum acting shear force    | $V_{Ed}$ | 9,07 | kN  | $V_{Ed} = \frac{1}{2} q l$                  |
|                               |          |      |     |                                             |

### Bending moment reinforcement

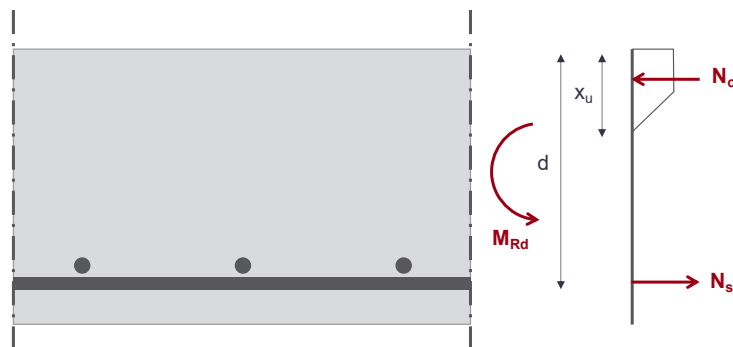


Figure K.51: Concrete cross-section

|                                  |          |         |     |                                                                              |
|----------------------------------|----------|---------|-----|------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 65564   | N   | $N_s = A_{sl} * f_{yd}$                                                      |
| Concrete compressive force       | $N_c$    |         | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                 |
| Concrete compressive zone height | $x_u$    | 7,35    | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$ |
|                                  |          |         |     |                                                                              |
| Bending moment resistance        | $M_{Rd}$ | 1877418 | Nmm | $M_{Rd} = N_s * (d - 0.39 x_u)$                                              |
|                                  |          | 1,88    | kNm |                                                                              |

|                                                                                  |               |       |                     |                                                                                                    |
|----------------------------------------------------------------------------------|---------------|-------|---------------------|----------------------------------------------------------------------------------------------------|
| Unity Check                                                                      | 1,00          | ≤     | 1,0                 |                                                                                                    |
| Distance from the end of the beam where the opening can be located               | x             | 0,221 | m                   | $\frac{qlx}{2} - \frac{qx^2}{2} - M_{Ed} = 0$                                                      |
| <b>Shear reinforcement</b>                                                       |               |       |                     |                                                                                                    |
| <b>Minimal reinforcement</b>                                                     |               |       |                     |                                                                                                    |
|                                                                                  | k             | 2,0   |                     | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                            |
| Smallest width of the cross-section in the tensile area                          | $b_w$         | 100   | mm                  |                                                                                                    |
| Reinforcement ratio for longitudinal reinforcement                               | $\rho_l$      | 0,048 |                     | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                          |
|                                                                                  | $C_{Rd,c}$    | 0,12  |                     | EN 1992-1-1/NB                                                                                     |
|                                                                                  | $V_{min}$     | 0,30  | N/mm <sup>2</sup>   | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                         |
|                                                                                  |               |       |                     |                                                                                                    |
|                                                                                  | $V_{Rd,c}$    | 3959  | N                   | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w * d \leq v_{min} * b_w * d$ |
|                                                                                  |               | 4     | kN                  | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                         |
|                                                                                  |               |       |                     |                                                                                                    |
| Unity Check                                                                      | 2,29          | ≤     | 1,0                 | Shear reinforcement required at the openings                                                       |
| <b>Maximum resistance</b>                                                        |               |       |                     |                                                                                                    |
| Coefficient taking into account the state of the stress in the compression chord | $\alpha_{cw}$ | 1     |                     | EN 1992-1-1/NB                                                                                     |
| Strength reduction factor for concrete cracked in shear                          | $v_1$         | 0,6   |                     | EN 1992-1-1/NB                                                                                     |
| Angle of the inclined struts                                                     | $\theta$      | 45    | °                   | Assumption                                                                                         |
|                                                                                  |               |       |                     |                                                                                                    |
| Limit value for shear resistance                                                 | $V_{Rd,max}$  | 17010 | N                   | $V_{Rd,max} = \alpha_{cw} * b_w * z * v_1 * f_{cd} / (\cot(\theta) + \tan(\theta))$                |
|                                                                                  |               | 17    | kN                  |                                                                                                    |
|                                                                                  |               |       |                     |                                                                                                    |
| Unity Check                                                                      | 0,53          | ≤     | 1,0                 | The cross-section is able to take the shear forces                                                 |
| <b>Required shear reinforcement</b>                                              |               |       |                     |                                                                                                    |
|                                                                                  | $A_{sw}/S_w$  | 0,74  | mm <sup>2</sup> /mm | $\frac{A_{sw}}{S_w} = \frac{V_{Ed} * \tan(\theta)}{z * f_{yd}}$                                    |
| Spacing of stirrups                                                              | $S_w$         | 38,44 | mm                  |                                                                                                    |

#### K.4.8 Check of manual calculations

The previous calculations are manual calculations done using Microsoft Excel. To ensure the accuracy of these calculations, a number of the manually calculated values are checked using Technosoft Construct. The results of the manual calculations and the Technosoft output for the bending moment resistances are in the same order of magnitude and therefore correspond sufficiently.

There is a discrepancy between the manual calculation and the Technosoft output for the shear force that can be taken by the concrete of the cross-section ( $V_{Rd,c}$ ). In the Technosoft calculation of this shear resistance, the effective height of the cross-section ( $d$ ) has a lower value than in the manual calculations. In the Technosoft calculations, a diameter for shear reinforcement is taken into consideration in the

determination of the effective height. In the manual calculation of the effective height, this diameter is taken as zero.

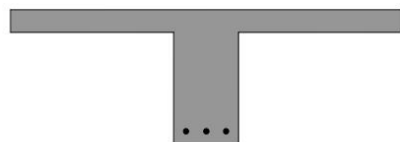
| Bending moment resistance – Longitudinal direction                                 |                                           |                          |                             |                              |                          |                          |                              |                              |      |
|------------------------------------------------------------------------------------|-------------------------------------------|--------------------------|-----------------------------|------------------------------|--------------------------|--------------------------|------------------------------|------------------------------|------|
| Manual calculation                                                                 | M <sub>Rd</sub>                           | 11,94                    | kNm                         |                              |                          |                          |                              |                              |      |
| Technosoft output                                                                  | M <sub>Rd</sub>                           | 12,8                     | kNm                         |                              |                          |                          |                              |                              |      |
| Toegepaste normen volgens Eurocode met Nederlandse NB                              |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| Belastingen                                                                        | NEN-EN 1990:2002                          | C2:2010                  | NB:2011(nl)                 |                              |                          |                          |                              |                              |      |
|                                                                                    | NEN-EN 1991-1-1:2002                      | C1:2009                  | NB:2011(nl)                 |                              |                          |                          |                              |                              |      |
| Beton                                                                              | NEN-EN 1992-1-1:2011(nl)                  | C2/A1:2015(nl)           | NB:2016(nl)                 |                              |                          |                          |                              |                              |      |
| Controle hoofdwapening. (B)                                                        |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| GEOMETRIE                                                                          |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| Elementtype                                                                        | : Balk                                    |                          |                             |                              |                          |                          |                              |                              |      |
| Betonkwaliteit                                                                     | : C30/37                                  |                          |                             |                              |                          |                          |                              |                              |      |
| Soort spanningsrekdiagram                                                          | : Parabolisch - rechthoekig diagram       |                          |                             |                              |                          |                          |                              |                              |      |
| Doorsnede vorm                                                                     | : T1                                      |                          |                             |                              |                          |                          |                              |                              |      |
| Afmetingen                                                                         | : b=595 h=204 b1=248 h1=170 b2=248 h2=170 |                          |                             |                              |                          |                          |                              |                              |      |
| Scheurvorming volgens art                                                          | : 7.3.4                                   |                          |                             |                              |                          |                          |                              |                              |      |
| Referentieperiode                                                                  | : 50 jaar                                 |                          |                             |                              |                          |                          |                              |                              |      |
|  |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| WAPENING                                                                           |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| Staalkwaliteit                                                                     | : B500B                                   |                          |                             |                              |                          |                          |                              |                              |      |
| Soort spanningsrekdiagram                                                          | : Bi-lineair diagram met klimmende tak    |                          |                             |                              |                          |                          |                              |                              |      |
| Beugeldiameter                                                                     | : 0                                       |                          |                             |                              |                          |                          |                              |                              |      |
| Toevallige inklemming                                                              | : nee                                     |                          |                             |                              |                          |                          |                              |                              |      |
| Toegepaste wapening                                                                | :                                         | Boven                    | Onder                       |                              |                          |                          |                              |                              |      |
| Breedte stort sleuf                                                                | :                                         | 0x12                     | 3x8                         |                              |                          |                          |                              |                              |      |
|                                                                                    |                                           | 50                       |                             |                              |                          |                          |                              |                              |      |
| Betondekking                                                                       |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| Milieu                                                                             | :                                         | Boven                    | Onder                       |                              |                          |                          |                              |                              |      |
|                                                                                    |                                           | XC1                      | XC1                         |                              |                          |                          |                              |                              |      |
| Gestort tegen bestaand beton                                                       | :                                         | Nee                      | Nee                         |                              |                          |                          |                              |                              |      |
| Element met plaatgeometrie                                                         | :                                         | Nee                      | Nee                         |                              |                          |                          |                              |                              |      |
| Specifieke kwaliteitsbeheersing                                                    | :                                         | Nee                      | Nee                         |                              |                          |                          |                              |                              |      |
| Oneffen beton oppervlak                                                            | :                                         | Nee                      | Nee                         |                              |                          |                          |                              |                              |      |
| Ondergrond                                                                         | :                                         | Glad / N.v.t.            | Glad / N.v.t.               |                              |                          |                          |                              |                              |      |
| Constructieklasse                                                                  | :                                         | S3                       | S3                          |                              |                          |                          |                              |                              |      |
| Grootste korrel                                                                    | :                                         | 16.0                     |                             |                              |                          |                          |                              |                              |      |
| Hoofdwapening                                                                      | :                                         | 1ste laag                | 1ste laag                   |                              |                          |                          |                              |                              |      |
| Nominale dekking                                                                   | :                                         | 17                       | 15                          |                              |                          |                          |                              |                              |      |
| Toegepaste dekking                                                                 | :                                         | 17                       | 15                          |                              |                          |                          |                              |                              |      |
| Gelijkwaardige diameter                                                            | :                                         | 12                       | 8                           |                              |                          |                          |                              |                              |      |
| C <sub>min,b</sub> C <sub>min,dur</sub> ΔC <sub>dur</sub>                          | :                                         | 12 10 0                  | 8 10 0                      |                              |                          |                          |                              |                              |      |
| C <sub>min</sub> ΔC <sub>dev</sub> C <sub>nom</sub>                                | :                                         | 12 5 17                  | 10 5 15                     |                              |                          |                          |                              |                              |      |
| BELASTING                                                                          |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| RESULTATEN                                                                         |                                           |                          |                             |                              |                          |                          |                              |                              |      |
| Nr                                                                                 | N <sub>Ed</sub><br>[kN]                   | M <sub>Ed</sub><br>[kNm] | N <sub>E;freq</sub><br>[kN] | M <sub>E;freq</sub><br>[kNm] | M <sub>Rd</sub><br>[kNm] | M <sub>Rd</sub><br>[kNm] | M <sub>R;freq</sub><br>[kNm] | M <sub>R;freq</sub><br>[kNm] | Opm. |
| 1                                                                                  | 0.0                                       | -7.5                     | 0.0                         | 0.0                          | 0.3                      | -12.8                    | 0.0                          | -14.1                        |      |

Figure K.52: Output Technosoft Construct Bending reinforcement in the longitudinal direction

Figure K.52: Output Technosoft Construct Bending reinforcement in the longitudinal direction

| Bending moment resistance – Transversal direction |            |      |     |
|---------------------------------------------------|------------|------|-----|
| Manual calculation top                            | $M_{Rd,t}$ | 0,85 | kNm |
| Manual calculation bottom                         | $M_{Rd,b}$ | 0,85 | kNm |
| Technosoft output top                             | $M_{Rd,t}$ | 0,9  | kNm |

|                                                           |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
|-----------------------------------------------------------|----------------------------------------|--------------------------|-----------------------------|------------------------------|-------------------------------------|--------------------------|-----------------------------------------------|------------------------------|------|
| Technosoft output bottom                                  |                                        | M <sub>Rd,b</sub>        | 0,9                         |                              | kNm                                 |                          |                                               |                              |      |
| Toegepaste normen volgens Eurocode met Nederlandse NB     |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| Belastingen                                               | NEN-EN 1990:2002                       |                          | C2:2010                     | NB:2011(nl)                  |                                     |                          |                                               |                              |      |
|                                                           | NEN-EN 1991-1-1:2002                   |                          | C1:2009                     | NB:2011(nl)                  |                                     |                          |                                               |                              |      |
| Beton                                                     | NEN-EN 1992-1-1:2011 (nl)              |                          | C2/A1:2015 (nl)             | NB:2016 (nl)                 |                                     |                          |                                               |                              |      |
| Controle hoofdwapening. (B)                               |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| GEOMETRIE                                                 |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| Elementtype                                               | : Balk                                 |                          |                             |                              |                                     |                          |                                               |                              |      |
| Betonkwaliteit                                            | : C30/37                               |                          |                             |                              |                                     |                          |                                               |                              |      |
| Soort spanningsrekdiagram                                 | : Parabolisch - rechthoekig diagram    |                          |                             |                              |                                     |                          |                                               |                              |      |
| Doorsnede vorm                                            | : Rechthoek                            |                          |                             |                              |                                     |                          |                                               |                              |      |
| Afmetingen                                                | : b=1000 h=34                          |                          |                             |                              |                                     |                          |                                               |                              |      |
| Scheurvorming volgens art                                 | : 7.3.4                                |                          |                             |                              |                                     |                          |                                               |                              |      |
| Referentieperiode                                         | : 50 jaar                              |                          |                             |                              |                                     |                          |                                               |                              |      |
| <div><div></div></div>                                    |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| WAPENING                                                  |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| Staalkwaliteit                                            | : B500B                                |                          |                             |                              |                                     |                          |                                               |                              |      |
| Soort spanningsrekdiagram                                 | : Bi-lineair diagram met klimmende tak |                          |                             |                              |                                     |                          |                                               |                              |      |
| Beugeldiameter                                            | : 0                                    |                          |                             |                              |                                     |                          |                                               |                              |      |
| Toevallige inklemming                                     | : nee                                  |                          |                             |                              |                                     |                          |                                               |                              |      |
| Toegepaste wapening                                       | :                                      | Boven                    | Onder                       |                              |                                     |                          |                                               |                              |      |
| Breedte stort sleuf                                       | :                                      | 10x4                     | 0x4                         |                              |                                     |                          |                                               |                              |      |
|                                                           |                                        | 50                       |                             |                              |                                     |                          |                                               |                              |      |
| Betondekking                                              |                                        | Boven                    | Onder                       |                              |                                     |                          |                                               |                              |      |
| Milieu                                                    | :                                      | XC1                      | XC1                         |                              |                                     |                          |                                               |                              |      |
| Gestort tegen bestaand beton                              | :                                      | Nee                      | Nee                         |                              |                                     |                          |                                               |                              |      |
| Element met plaatgeometrie                                | :                                      | Nee                      | Nee                         |                              |                                     |                          |                                               |                              |      |
| Specifieke kwaliteitsbeheersing                           | :                                      | Nee                      | Nee                         |                              |                                     |                          |                                               |                              |      |
| Oneffen beton oppervlak                                   | :                                      | Nee                      | Nee                         |                              |                                     |                          |                                               |                              |      |
| Ondergrond                                                | :                                      | Glad / N.v.t.            | Glad / N.v.t.               |                              |                                     |                          |                                               |                              |      |
| Constructieklasse                                         | :                                      | S3                       | S3                          |                              |                                     |                          |                                               |                              |      |
| Grootste korrel                                           | :                                      | 16.0                     |                             |                              |                                     |                          |                                               |                              |      |
| Hoofdwapening                                             | :                                      | 1ste laag                | 1ste laag                   |                              |                                     |                          |                                               |                              |      |
| Nominale dekking                                          | :                                      | 15                       | 15                          |                              |                                     |                          |                                               |                              |      |
| Toegepaste dekking                                        | :                                      | 15                       | 15                          |                              |                                     |                          |                                               |                              |      |
| Gelijkwaardige diameter                                   | :                                      | 4                        | 4                           |                              |                                     |                          |                                               |                              |      |
| C <sub>min,b</sub> C <sub>min,dur</sub> ΔC <sub>dur</sub> | :                                      | 4 10 0                   | 4 10 0                      |                              |                                     |                          |                                               |                              |      |
| C <sub>min</sub> ΔC <sub>dev</sub> C <sub>nom</sub>       | :                                      | 10 5 15                  | 10 5 15                     |                              |                                     |                          |                                               |                              |      |
| BELASTING                                                 |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| RESULTATEN                                                |                                        |                          |                             |                              |                                     |                          |                                               |                              |      |
| Nr                                                        | N <sub>Ed</sub><br>[kN]                | M <sub>Ed</sub><br>[kNm] | N <sub>E;freq</sub><br>[kN] | M <sub>E;freq</sub><br>[kNm] | Sterkte<br>M <sub>Rd</sub><br>[kNm] | M <sub>Rd</sub><br>[kNm] | Scheurvorming<br>M <sub>R;freq</sub><br>[kNm] | M <sub>R;freq</sub><br>[kNm] | Opm. |
| 1                                                         | 0.0                                    | -0.6                     | 0.0                         | 0.0                          | 0.9                                 | -0.4                     | 0.0                                           | -0.0                         | 11   |

Figure K.53: Output Technosoft Construct Bending reinforcement in transversal direction top

Figure K.53: Output Technosoft Construct Bending reinforcement in transversal direction top



### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=34                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalilige inklemming    | : nee                                  |
| Toegepaste wapening       | : Boven 0x4 Onder 10x4                 |
| Breedte stort sleuf       | : 50                                   |

#### Betondekking

|                                 |                               |
|---------------------------------|-------------------------------|
| Milieu                          | : Boven XC1 Onder XC1         |
| Gestort tegen bestaand beton    | : Nee Nee                     |
| Element met plaatgeometrie      | : Nee Nee                     |
| Specifieke kwaliteitsbeheersing | : Nee Nee                     |
| Oneffen beton oppervlak         | : Nee Nee                     |
| Ondergrond                      | : Glad / N.v.t. Glad / N.v.t. |
| Constructieklasse               | : S3 S3                       |
| Grootste korrel                 | : 16.0                        |

|                                            |                       |
|--------------------------------------------|-----------------------|
| Hoofdwapening                              | : 1ste laag 1ste laag |
| Nominale dekking                           | : 15 15               |
| Toegepaste dekking                         | : 15 15               |
| Gelijkwaardige diameter                    | : 4 4                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 4 10 0 4 10 0       |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 10 5 15 10 5 15     |

#### BELASTING

#### RESULTATEN

| Nr | Sterkte          |                   |                      |                       | Scheurvorming         |                       | Opm.         |
|----|------------------|-------------------|----------------------|-----------------------|-----------------------|-----------------------|--------------|
|    | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] |              |
| 1  | 0.0              | -0.3              | 0.0                  | 0.0                   | 0.4                   | -0.9                  | 0.0 -0.0 167 |

Figure K.54: Output Technosoft Construct Bending reinforcement in transversal direction top

### Shear force resistance – Longitudinal direction

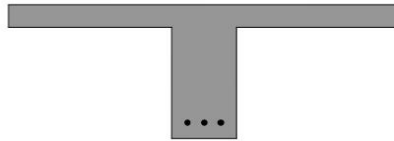
|                    |            |       |    |
|--------------------|------------|-------|----|
| Manual calculation | $V_{Rd,c}$ | 17    | kN |
| Technosoft output  | $V_{Rd,c}$ | 12,57 | kN |

**Toegepaste normen volgens Eurocode met Nederlandse NB**

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

**Dwarskracht en wringing. (B)****GEOMETRIE**

|                           |                                           |
|---------------------------|-------------------------------------------|
| Elementtype               | : Balk                                    |
| Betonkwaliteit            | : C30/37                                  |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram       |
| Doorsnede vorm            | : T1                                      |
| Afmetingen                | : b=595 h=204 b1=248 h1=170 b2=248 h2=170 |
| Referentieperiode         | : 50 jaar                                 |

**WAPENING**

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Toevallige inklemming     | : nee                                  |
| Toegepaste wapening       | : Boven 0x4 Onder 3x8                  |
| Breedte stort sleuf       | : 50                                   |

**Betondekking**

|                                            |   |               |               |
|--------------------------------------------|---|---------------|---------------|
| Milieu                                     | : | Boven XC1     | Onder XC1     |
| Gestort tegen bestaand beton               | : | Nee           | Nee           |
| Element met plaatgeometrie                 | : | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing            | : | Nee           | Nee           |
| Oneffen beton oppervlak                    | : | Nee           | Nee           |
| Ondergrond                                 | : | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                          | : | S3            | S3            |
| Grootste korrel                            | : | 16.0          |               |
| Hoofdwapening                              | : | 2de laag      | 2de laag      |
| Nominale dekking                           | : | 15            | 15            |
| Toegepaste dekking                         | : | 20            | 20            |
| Gelijkwaardige diameter                    | : | 4             | 8             |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : | 4 10 0        | 8 10 0        |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : | 10 5 15       | 10 5 15       |

|                                            |                        |           |                                   |
|--------------------------------------------|------------------------|-----------|-----------------------------------|
| Beugel / Verdeelwapening                   | :                      | 1ste laag | 1ste laag                         |
| Nominale dekking                           | :                      | 15        | 15                                |
| Toegepaste dekking                         | :                      | 15        | 15                                |
| Gelijkwaardige diameter                    | :                      | 5         | 5                                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | :                      | 5 10 0    | 5 10 0                            |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | :                      | 10 5 15   | 10 5 15                           |
| Minimale beugelafstand                     | :                      | 50        | Theta [graden] : 45.0             |
| Uitg.p. inw.hefboomsarm z                  | :                      | 0,9*d     |                                   |
| <b>BELASTING</b>                           |                        |           |                                   |
| NEd                                        | [kN] :                 | 0.0       | MEd [kNm] : 0.0                   |
| VEd                                        | [kN] :                 | 9.1       | TEd [kNm] : 0.0                   |
| Q-permanent                                | [kN/m] :               | 0.0       | Veiligheidsklasse : 3             |
| Q-veranderlijk                             | [kN/m] :               | 0.0       | Gamma-permanent : 1.32            |
| L                                          | [m] :                  | 3.3       | Gamma-veranderlijk : 1.65         |
|                                            |                        |           | X [m] : 0.0                       |
| <b>RESULTATEN</b>                          |                        |           |                                   |
| Beugeldiameter                             | [mm] :                 | 5         | z [mm] : 162.00                   |
| Trekzijde                                  | :                      | Onder     | Wapeningsverhouding : 0.00141     |
| Dwarskracht                                |                        |           | Wringing                          |
| $V_{Rd,max}$                               | [kN] :                 | 84.68     | $T_{Rd,max}$ [kNm] : 4.00         |
| $V_{Ed}$                                   | [kN] :                 | 9.07      | $T_{Ed}$ [kNm] : 0.00             |
| $V_{Rd,c}$                                 | [kN] :                 | 12.57     | $T_{RD,c}$ [kNm] : 1.02           |
| A-opg                                      | [mm <sup>2</sup> /m] : | 0.00      | A-langs [mm <sup>2</sup> ] : 0.00 |
| A-bgl                                      | [mm <sup>2</sup> /m] : | 0.00      | A-bgl [mm <sup>2</sup> /m] : 0.00 |
| H.o.h. afstand                             | [mm] :                 | 300.0     | Aant. beugelsneden/drsn: 1        |

Figure K.55: Output Technosoft Construct shear reinforcement in the longitudinal direction

#### K.4.9 Steel beam



Figure K.56: Schematisation of the load distribution on the steel beam

The spread-out point loads from the ribs on the steel beam are schematised as a distributed load, as shown in Figure K.56. The load on the beam include the own weight of the beam and the weight of the floor elements on both sides of the beam.

| Input                   |            |          |                 |                          |
|-------------------------|------------|----------|-----------------|--------------------------|
| Dimensions              |            |          |                 |                          |
| Number of ribs          | n          | 7        |                 |                          |
| Span                    | L          | 6100     | mm              |                          |
| Profile properties      |            |          |                 |                          |
| RHS 200x100 / 8         |            |          |                 | (Eurocode Applied, n.d.) |
| Height                  | h          | 200      | mm              |                          |
| Width                   | b          | 100      | mm              |                          |
| Wall thickness          | t          | 8        | mm              |                          |
| Outer rounding radius   | r          | 12       | mm              |                          |
| Area                    | A          | 4480     | mm <sup>2</sup> |                          |
| Second moment of area   | $I_y$      | 22300000 | mm <sup>4</sup> |                          |
| Plastic section modulus | $W_{y,pl}$ | 282000   | mm <sup>3</sup> |                          |
| Weight                  | G          | 35,1     | kg/m            |                          |
|                         |            | 0,34     | kN/m            |                          |
| Section classification  | Class      | 1        |                 |                          |

|                                       |               |           |                   |                                                     |
|---------------------------------------|---------------|-----------|-------------------|-----------------------------------------------------|
|                                       |               |           |                   |                                                     |
| <b>Steel properties</b>               |               |           |                   |                                                     |
| <b>S355</b>                           |               |           |                   |                                                     |
| Design yield stress                   | $f_y$         | 355       | N/mm <sup>2</sup> |                                                     |
| Young's modulus                       | $E$           | 210000    | N/mm <sup>2</sup> |                                                     |
|                                       |               |           |                   |                                                     |
| Partial factor                        | $\gamma_{M0}$ | 1,0       |                   |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Loads</b>                          |               |           |                   |                                                     |
| Load from floor element on beam (ULS) | $V_{ULS}$     | 9,07      | kN                |                                                     |
| Load from floor element on beam (SLS) | $V_{SLS}$     | 4,48      | kN                |                                                     |
|                                       |               |           |                   |                                                     |
| Distributed load (ULS)                | $q_{ULS}$     | 21,16     | kN/m              | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$           |
| Distributed load (SLS)                | $q_{SLS}$     | 10,63     | kN/m              | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$           |
|                                       |               |           |                   |                                                     |
| <b>Load distribution</b>              |               |           |                   |                                                     |
| Bending moment                        | $M_{Ed}$      | 98,4      | kNm               | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$                  |
| Shear force                           | $V_{Ed}$      | 64,5      | kN                | $V_{Ed} = \frac{1}{2} q_{ULS} L$                    |
|                                       |               |           |                   |                                                     |
| <b>Bending resistance</b>             |               |           |                   |                                                     |
| Bending moment resistance             | $M_{Rd}$      | 100110000 | Nmm               | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$         |
|                                       |               | 100       | kNm               |                                                     |
|                                       |               |           |                   |                                                     |
| Unity check                           | 0,98          | ≤         | 1,0               |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Shear resistance</b>               |               |           |                   |                                                     |
| Shear area                            | $A_v$         | 2986,667  | mm <sup>2</sup>   | $A_v = \frac{A * h}{b + h}$                         |
|                                       |               |           |                   |                                                     |
| Shear force resistance                | $V_{Rd}$      | 612145    | N                 | $V_{Rd} = \frac{A_v (f_y / \sqrt{3})}{\gamma_{M0}}$ |
|                                       |               | 612       | kN                |                                                     |
|                                       |               |           |                   |                                                     |
| Unity check                           | 0,105         | ≤         | 1,0               |                                                     |
|                                       |               |           |                   |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Deflection (SLS)</b>               |               |           |                   |                                                     |
| Maximum deflection                    | $w_{max}$     | 12,2      | mm                | $w_{max} = \frac{L}{500}$                           |
| Deflection                            | $w$           | 0,00      | mm                | $w = \frac{5}{384} * \frac{qL}{EI}$                 |
|                                       |               |           |                   |                                                     |
|                                       | 0             | mm        | ≤                 | 12,2 mm                                             |

## Input

| Dimensions                            |                   |           |                   |                                             |
|---------------------------------------|-------------------|-----------|-------------------|---------------------------------------------|
| Number of ribs                        | n                 | 7         |                   |                                             |
| Span                                  | L                 | 6100      | mm                |                                             |
|                                       |                   |           |                   |                                             |
| Profile properties                    |                   |           |                   |                                             |
| RHS 180x100 / 8                       |                   |           |                   | (Eurocode Applied, n.d.)                    |
| Height                                | h                 | 180       | mm                |                                             |
| Width                                 | b                 | 100       | mm                |                                             |
| Wall thickness                        | t                 | 10        | mm                |                                             |
| Outer rounding radius                 | r                 | 15        | mm                |                                             |
| Area                                  | A                 | 5093      | mm <sup>2</sup>   |                                             |
| Second moment of area                 | I <sub>y</sub>    | 20360000  | mm <sup>4</sup>   |                                             |
| Plastic section modulus               | W <sub>y,pl</sub> | 287900    | mm <sup>3</sup>   |                                             |
| Weight                                | G                 | 40        | kg/m              |                                             |
|                                       |                   | 0,39      | kN/m              |                                             |
| Section classification                | Class             | 1         |                   |                                             |
|                                       |                   |           |                   |                                             |
| Steel properties                      |                   |           |                   |                                             |
| S355                                  |                   |           |                   |                                             |
| Design yield stress                   | f <sub>y</sub>    | 355       | N/mm <sup>2</sup> |                                             |
| Young's modulus                       | E                 | 210000    | N/mm <sup>2</sup> |                                             |
|                                       |                   |           |                   |                                             |
| Partial factor                        | γ <sub>M0</sub>   | 1,0       |                   |                                             |
|                                       |                   |           |                   |                                             |
| Loads                                 |                   |           |                   |                                             |
| Load from floor element on beam (ULS) | V <sub>ULS</sub>  | 9,07      | kN                |                                             |
| Load from floor element on beam (SLS) | V <sub>SLS</sub>  | 4,48      | kN                |                                             |
|                                       |                   |           |                   |                                             |
| Distributed load (ULS)                | q <sub>ULS</sub>  | 21,21     | kN/m              | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$   |
| Distributed load (SLS)                | q <sub>SLS</sub>  | 10,67     | kN/m              | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$   |
|                                       |                   |           |                   |                                             |
| Load distribution                     |                   |           |                   |                                             |
| Bending moment                        | M <sub>Ed</sub>   | 98,6      | kNm               | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$          |
| Shear force                           | V <sub>Ed</sub>   | 64,7      | kN                | $V_{Ed} = \frac{1}{2} q_{ULS} L$            |
|                                       |                   |           |                   |                                             |
| Bending resistance                    |                   |           |                   |                                             |
| Bending moment resistance             | M <sub>Rd</sub>   | 102204500 | Nmm               | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$ |
|                                       |                   | 102       | kNm               |                                             |
|                                       |                   |           |                   |                                             |
| Unity check                           | 0,97              | ≤         | 1,0               |                                             |
|                                       |                   |           |                   |                                             |
| Shear resistance                      |                   |           |                   |                                             |
| Shear area                            | A <sub>v</sub>    | 3274      | mm <sup>2</sup>   | $A_v = \frac{A * h}{b + h}$                 |

|                         |           |        |     |                                                  |
|-------------------------|-----------|--------|-----|--------------------------------------------------|
| Shear force resistance  | $V_{Rd}$  | 671052 | N   | $V_{Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}}$ |
|                         |           | 671    | kN  |                                                  |
| Unity check             | 0,096     | ≤      | 1,0 |                                                  |
| <b>Deflection (SLS)</b> |           |        |     |                                                  |
| Maximum deflection      | $w_{max}$ | 12,2   | mm  | $w_{max} = \frac{L}{500}$                        |
| Deflection              | $w$       | 0,00   | mm  | $w = \frac{5}{384} * \frac{qL^4}{EI}$            |
|                         | 0         | mm     | ≤   | 12,2 mm                                          |

## K.5 Option B.ii: Short span with accessibility from the top

### K.5.1 Input

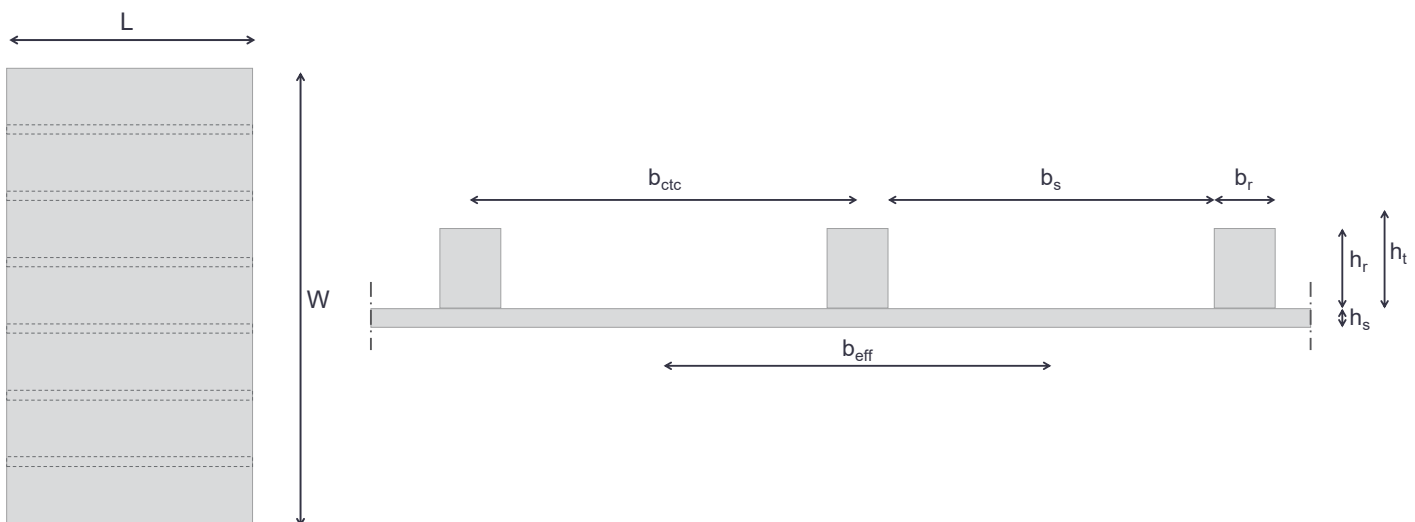


Figure K.57: Indication of the dimensions

| Dimensions                             |           |      |    |                                                                         |
|----------------------------------------|-----------|------|----|-------------------------------------------------------------------------|
| Span                                   | $L$       | 3300 | mm |                                                                         |
| Width                                  | $W$       | 6100 | mm |                                                                         |
| Number of ribs                         |           | 7    |    |                                                                         |
| Height slab                            | $h_s$     | 34   | mm | $\geq \max[\varphi_{t,t}; \varphi_{t,b}; \varphi_l] + 2 * c_{nom} = 34$ |
| Height rib                             | $h_r$     | 170  | mm | $\geq 170$ mm                                                           |
| Total height                           | $h_t$     | 204  | mm | $h_t = h_s + h_r$                                                       |
| Width rib                              | $b_r$     | 115  | mm |                                                                         |
| Space between ribs                     | $b_s$     | 756  | mm | $\geq 170$ mm                                                           |
| Centre to centre distance between ribs | $b_{ctc}$ | 871  | mm | $b_{ctc} = b_r + b_s$                                                   |

|                                                    |                  |      |                   |                                                         |
|----------------------------------------------------|------------------|------|-------------------|---------------------------------------------------------|
|                                                    |                  |      |                   |                                                         |
| <b>Concrete properties</b>                         |                  |      |                   |                                                         |
| C30/37                                             |                  |      |                   |                                                         |
| Density                                            | $\rho_{rep}$     | 25   | kN/m <sup>3</sup> |                                                         |
| Characteristic cylinder strength                   | $f_{ck}$         | 30   | N/mm <sup>2</sup> |                                                         |
| Partial safety factor concrete                     | $\gamma_c$       | 1,5  |                   |                                                         |
| Design compressive strength                        | $f_{cd}$         | 20   | N/mm <sup>2</sup> |                                                         |
| Design tensile strength                            | $f_{ctd}$        | 1,35 | N/mm <sup>2</sup> |                                                         |
| Mean tensile strength                              | $f_{ctm}$        | 2,9  | N/mm <sup>2</sup> |                                                         |
|                                                    |                  |      |                   |                                                         |
| <b>Reinforcement properties</b>                    |                  |      |                   |                                                         |
| <b>Longitudinal reinforcement</b>                  |                  |      |                   |                                                         |
| Diameter longitudinal reinforcement                | $\varphi_l$      | 4    | mm                |                                                         |
| Number of longitudinal reinforcement bars          | $n$              | 11   |                   |                                                         |
| Surface area longitudinal reinforcement            | $A_{sl}$         | 138  | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$              |
| Spacing of longitudinal reinforcement              | $s_l$            | 54   | mm                | $s_l = \frac{b_{eff}}{n}$                               |
| Effective height of the cross-section              | $d_l$            | 187  | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$         |
|                                                    |                  |      |                   |                                                         |
| <b>Transversal reinforcement top</b>               |                  |      |                   |                                                         |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars top       | $n$              | 10   |                   |                                                         |
| Surface area transversal reinforcement bars top    | $A_{st,t}$       | 126  | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$        |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$        | 100  | mm                | $s_{t,t} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 17   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
|                                                    |                  |      |                   |                                                         |
| <b>Transversal reinforcement bottom</b>            |                  |      |                   |                                                         |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$  | 4    | mm                |                                                         |
| Number of transversal reinforcement bars bottom    | $n$              | 10   |                   |                                                         |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$       | 126  | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$        |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$        | 100  | mm                | $s_{t,b} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 17   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$         |
|                                                    |                  |      |                   |                                                         |
| <b>Concrete cover</b>                              |                  |      |                   |                                                         |
| Minimum cover due to environmental conditions      | $c_{min,dur}$    | 10   | mm                | XC1                                                     |
| Minimum cover due to bond requirement              | $c_{min,b}$      | 8    | mm                | EN 1992-1-1                                             |
| Minimum cover                                      | $c_{min}$        | 10   | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10\text{mm}\}$ |
| Allowance in design for deviation                  | $\Delta c_{dev}$ | 5    | mm                | EN 1992-1-1/NB                                          |
| Nominal cover                                      | $c_{nom}$        | 15   | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$                    |
|                                                    |                  |      |                   |                                                         |



| Reinforcement steel         |            |      |                   |  |
|-----------------------------|------------|------|-------------------|--|
| B500 B                      |            |      |                   |  |
| Yield strength              | $f_{yk}$   | 500  | N/mm <sup>2</sup> |  |
| Partial safety factor steel | $\gamma_s$ | 1,15 |                   |  |
| Design yield stress         | $f_{yd}$   | 435  | N/mm <sup>2</sup> |  |

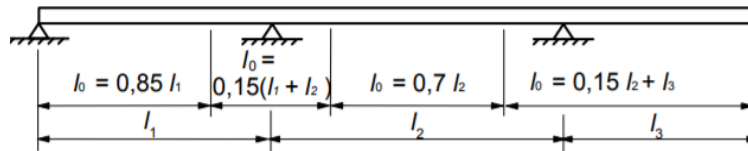


Figure K.58: Definition of  $l_0$ , for calculation of effective flange width from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

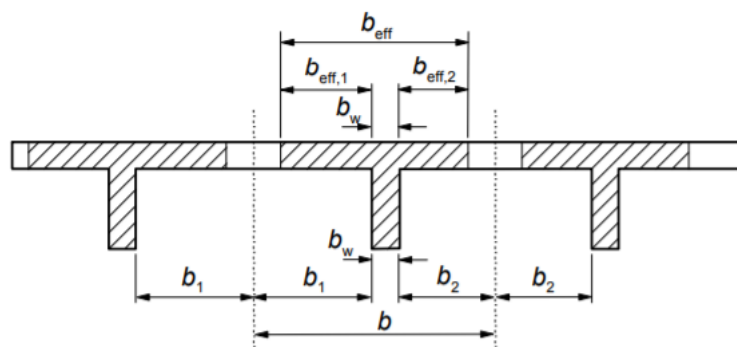


Figure K.59: Effective flange width parameters from EN 1992-1-1 (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |      |    |                                              |
|------------------------|------|----|----------------------------------------------|
| $l_1$                  | 3300 | mm | $l_1 = L$                                    |
| $l_0$                  | 1650 | mm | $l_0 = 0,85 l_1$                             |
|                        |      |    |                                              |
| $b_1$                  | 372  | mm | $b_1 = 0.5 * b_s$                            |
| $b_2$                  | 372  | mm | $b_2 = 0.5 * b_s$                            |
| $b_w$                  | 128  | mm | $b_w = b_r$                                  |
| $b$                    | 871  | mm | $b = b_{ctc}$                                |
|                        |      |    |                                              |
| $b_{eff,1}$            | 241  | mm | $b_{eff,1} = 0.2 b_1 + 0.1 l_0 \leq 0.2 l_0$ |
| $b_{eff,2}$            | 241  | mm | $b_{eff,2} = 0.2 b_2 + 0.1 l_0 \leq 0.2 l_0$ |
|                        |      |    |                                              |
| $b_{eff}$              | 596  | mm | $b_{eff} = \sum b_{eff,i} + b_w \leq b$      |

## K.5.2 Loads

| Permanent loads   |                |      |                   |                               |
|-------------------|----------------|------|-------------------|-------------------------------|
| Slab              | $g_{slab}$     | 0,85 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$ |
| Rib               | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$  |
| Ceiling panels    | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                               |
| Building services | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)          |
|                   |                |      |                   |                               |

|                                                     |              |      |                   |                                                                                                 |
|-----------------------------------------------------|--------------|------|-------------------|-------------------------------------------------------------------------------------------------|
| Total deadload longitudinal direction               | $g_{k,l}$    | 1,67 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                     |
| Total deadload transversal direction                | $g_{k,t}$    | 1,91 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1 m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1 m]$ |
| <b>Variable load</b>                                |              |      |                   |                                                                                                 |
| Variable floor load residential buildings           | $q_{res}$    | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                                                  |
| Movable partitions                                  | $q_{part}$   | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                                     |
| Total variable floor load                           | $q_{tot}$    | 2,55 | kN/m <sup>2</sup> |                                                                                                 |
| Total variable floor load in longitudinal direction | $q_{k,l}$    | 2,22 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                                                   |
| Total variable floor load in transversal direction  | $q_{k,t}$    | 2,55 | kN/m              | $q_{k,t} = q_{tot} * [1 m]$                                                                     |
| <b>Load combination ULS</b>                         |              |      |                   |                                                                                                 |
| Partial factor for permanent loads                  | $\gamma_G$   | 1,35 |                   | EN 1990/NB                                                                                      |
| Partial factor for variable loads                   | $\gamma_Q$   | 1,5  |                   | EN 1990/NB                                                                                      |
| ULS load combination in longitudinal direction      | $q_{ULS,l}$  | 5,58 | kN/m              | EN 1990 6.10a                                                                                   |
| ULS load combination in transversal direction       | $q_{ULS,t}$  | 6,40 | kN/m              | EN 1990 6.10a                                                                                   |
| <b>Load combination SLS</b>                         |              |      |                   |                                                                                                 |
| Factor for frequent value of a variable action      | $\psi_{1,1}$ | 0,5  |                   | EN 1990                                                                                         |
| SLS load combination in longitudinal direction      | $q_{SLS,l}$  | 2,78 | kN/m              | EN 1990 6.15a                                                                                   |
| SLS load combination in transversal direction       | $q_{SLS,t}$  | 3,19 | kN/m              | EN 1990 6.15a                                                                                   |

### K.5.3 Ultimate limit state – Longitudinal direction

#### Load distribution

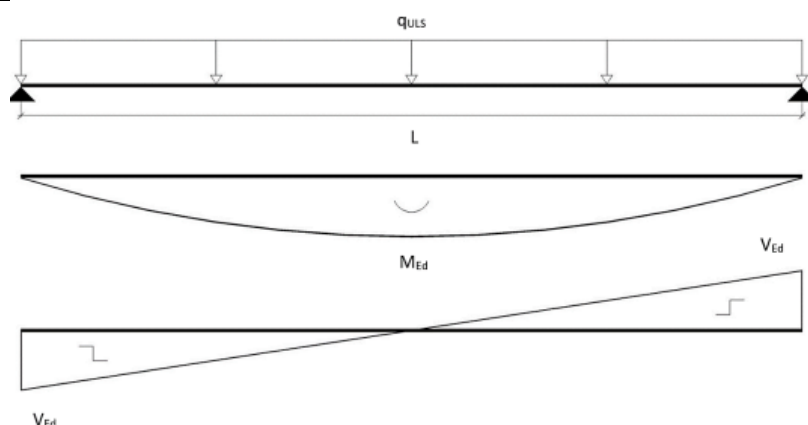
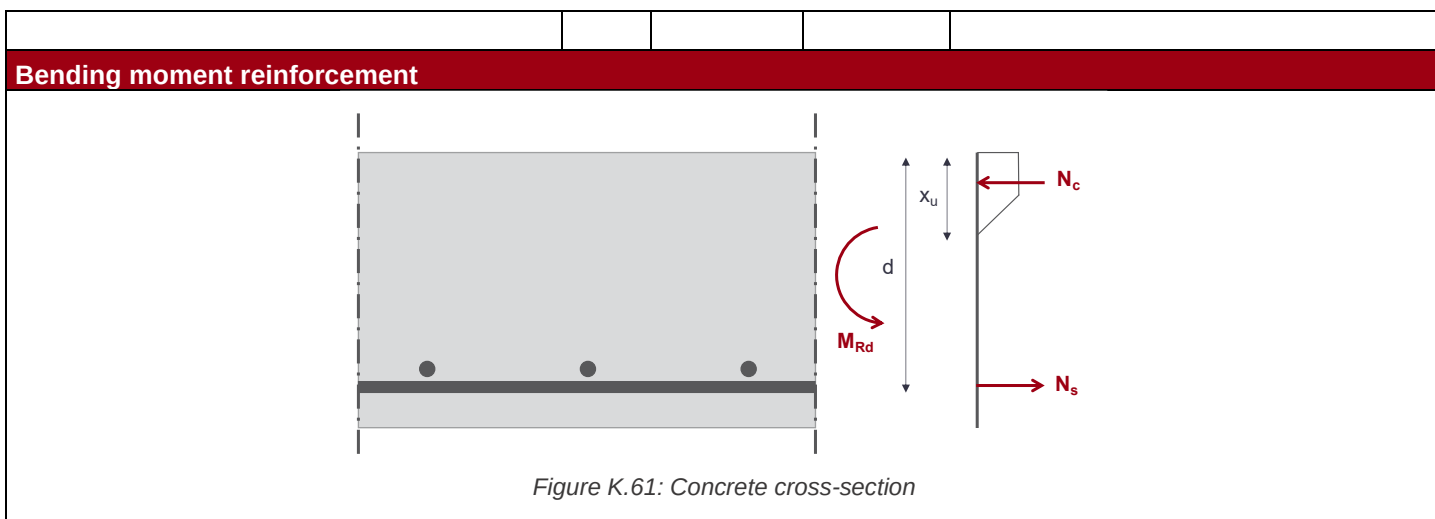


Figure K.60: Load distribution in the longitudinal direction

|                               |          |      |     |                                      |
|-------------------------------|----------|------|-----|--------------------------------------|
| Maximum acting bending moment | $M_{Ed}$ | 7,60 | kNm | $M_{Ed} = \frac{1}{8} q_{ULS,l} l^2$ |
| Maximum acting shear force    | $V_{Ed}$ | 9,21 | kN  | $V_{Ed} = \frac{1}{2} q_{ULS,l} l$   |



|                                  |          |          |     |                                                                              |
|----------------------------------|----------|----------|-----|------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 60100    | N   | $N_s = A_{sl} * f_{yd}$                                                      |
| Concrete compressive force       | $N_c$    |          | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                 |
| Concrete compressive zone height | $x_u$    | 34,84    | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$ |
| Bending moment resistance        | $M_{Rd}$ | 10422077 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                               |
|                                  |          | 10,42    | kNm |                                                                              |
| Unity Check                      | 0,73     | ≤        | 1,0 |                                                                              |

### Shear reinforcement

#### Minimal reinforcement

|                                                         |            |       |                   |                                                                                                    |
|---------------------------------------------------------|------------|-------|-------------------|----------------------------------------------------------------------------------------------------|
|                                                         | k          | 2,0   |                   | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                            |
| Smallest width of the cross-section in the tensile area | $b_w$      | 115   | mm                |                                                                                                    |
| Reinforcement ratio for longitudinal reinforcement      | $\rho_l$   | 0,02  |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                          |
|                                                         | $C_{Rd,c}$ | 0,12  |                   | EN 1992-1-1/NB                                                                                     |
|                                                         | $v_{min}$  | 0,30  | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                         |
|                                                         | $V_{Rd,c}$ | 20205 | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w * d \leq v_{min} * b_w * d$ |
|                                                         |            | 20,21 | kN                |                                                                                                    |
| Unity Check                                             | 0,46       | ≤     | 1                 | No shear reinforcement required                                                                    |

### K.5.4 Ultimate limit state – Transversal direction

#### Load distribution

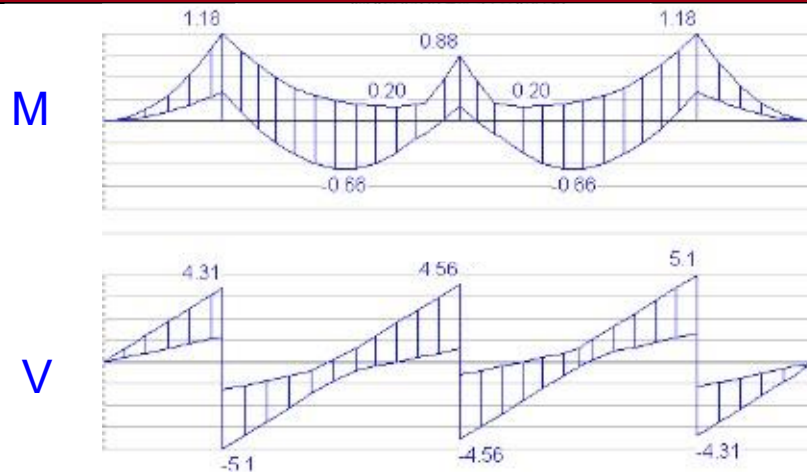


Figure K.62: Load distribution in transversal direction (enveloping fundamental combination using Technosoft Liggers)

|                                         |                 |      |     |  |
|-----------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment at top    | $M_{Ed,top}$    | 0,61 | kNm |  |
| Maximum acting bending moment at bottom | $M_{Ed,bottom}$ | 0,36 | kNm |  |
| Maximum acting shear force              | $V_{Ed}$        | 3,26 | kN  |  |
|                                         |                 |      |     |  |

#### Bending moment reinforcement

##### Bending moment reinforcement at the top

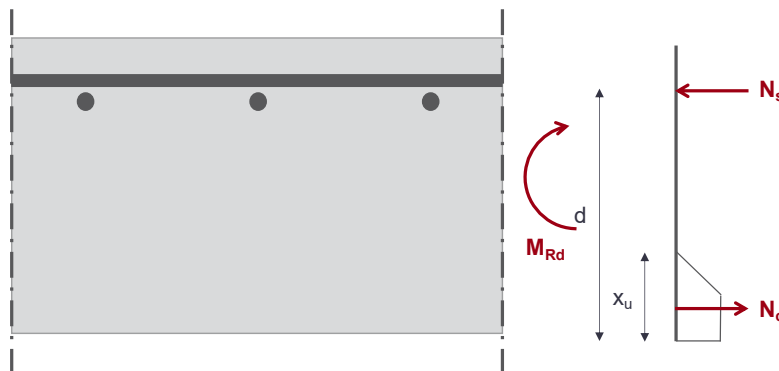


Figure K.63: Concrete cross-section top reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 54636  | N   | $N_s = A_{st,t} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,64   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 851205 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,85   | kNm |                                                                                   |
| Unity Check                      | 0,72     | ≤      | 1,0 |                                                                                   |

### Bending moment reinforcement at the bottom

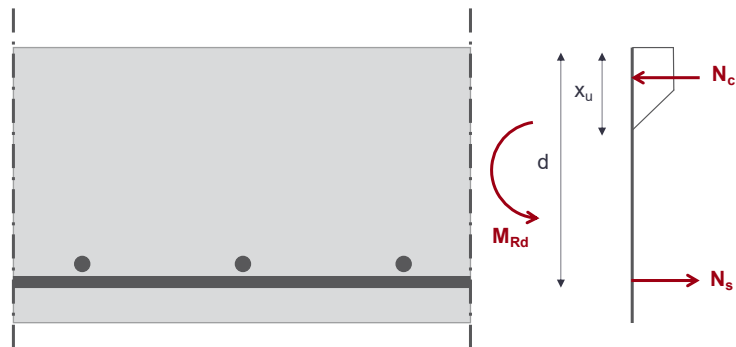


Figure K.64: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 54636  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 3,64   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 851205 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,85   | kNm |                                                                                   |
| Unity Check                      | 0,42     | ≤      | 1   |                                                                                   |

### Shear in web-flange interface

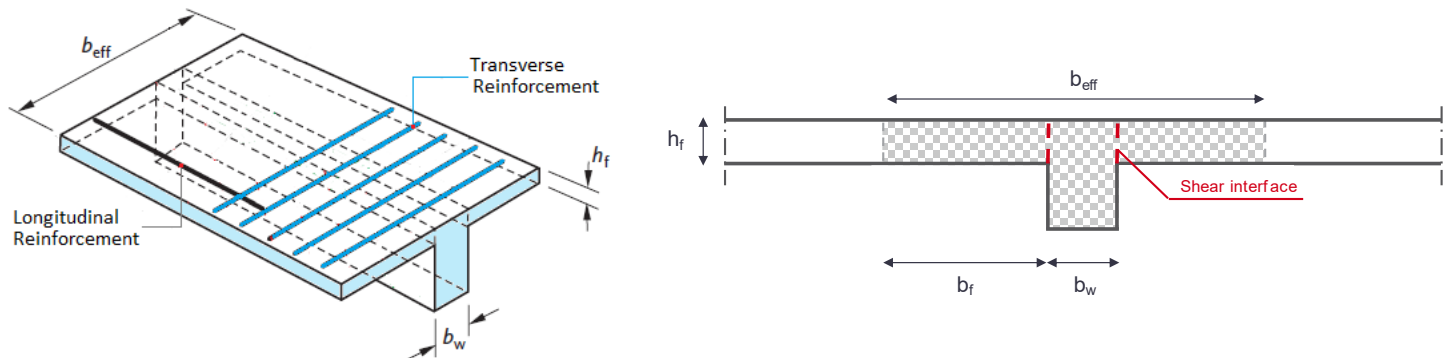


Figure K.65: Parameters for shear in the web-flange interface (Walraven, 2011)

|                 |          |      |                   |                                                                   |
|-----------------|----------|------|-------------------|-------------------------------------------------------------------|
| Width of flange | $b_f$    | 241  | mm                |                                                                   |
| Shear stress    | $v_{Ed}$ | 0,23 | N/mm <sup>2</sup> | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$        |
|                 | $k$      | 0,4  |                   | EN 1992-1-1/NB                                                    |
|                 | 0,23     | ≤    | 0,54              | $v_{ed} \leq k * f_{ctd}$<br>No transverse reinforcement required |

### K.5.5 Serviceability limit state

| Crack control                                                                                                            |                |        |                   |                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------|----------------|--------|-------------------|--------------------------------------------------------------------------------------|
| Maximum areas of reinforcement                                                                                           |                |        |                   |                                                                                      |
| Absolute value of the maximum stress permitted in the reinforcement immediately after the formation of the crack         | $\sigma_s$     | 500    | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which takes account of the stress distribution within the section immediately prior to cracking              | $k_c$          | 0,4    |                   | EN 1992-1-1                                                                          |
| Mean value of the tensile strength of the concrete effective at the times when the cracks may first be expected to occur | $f_{ct,eff}$   | 2,9    | N/mm <sup>2</sup> | EN 1992-1-1                                                                          |
| Coefficient which allows for the effect of non-uniform self-equilibrating                                                |                |        |                   |                                                                                      |
| Slab                                                                                                                     | $k$            | 1,1862 |                   | EN 1992-1-1                                                                          |
| Rib                                                                                                                      | $k$            | 1,00   |                   | EN 1992-1-1                                                                          |
| Area or concrete within the tensile zone                                                                                 |                |        |                   |                                                                                      |
| Rib (longitudinal direction)                                                                                             | $A_{ct,r}$     | 9775   | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the top (transversal direction)                                                               | $A_{ct,t,t}$   | 17000  | mm <sup>2</sup>   |                                                                                      |
| Slab with reinforcement at the bottom (transversal direction)                                                            | $A_{ct,t,b}$   | 17000  | mm <sup>2</sup>   |                                                                                      |
| Minimum area of reinforcement                                                                                            |                |        |                   |                                                                                      |
| Rib in longitudinal direction                                                                                            | $A_{smin,l,r}$ | 23     | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab in transversal direction, top                                                                                       | $A_{smin,t,t}$ | 47     | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| Slab in transversal direction, bottom                                                                                    | $A_{smin,t,b}$ | 47     | mm <sup>2</sup>   | $A_{s,min} * \sigma_s = k_c * k * f_{ct,eff} * A_{ct}$                               |
| The minimum areas or reinforcement are included in the reinforcement requirements in Appendix K.5.6                      |                |        |                   |                                                                                      |
| Restrictions for bar diameters and spacing                                                                               |                |        |                   |                                                                                      |
| Limit value crack width                                                                                                  | $w_{max}$      | 0,4    | mm                | EN 1992-1-1/NB                                                                       |
| Longitudinal direction                                                                                                   |                |        |                   |                                                                                      |
| Bending moment in SLS                                                                                                    | $M_{Efreq}$    | 3,78   | kNm               | $M_{Ed} = \frac{1}{8} q_{SLS,l} l^2$                                                 |
| Bending moment resistance                                                                                                | $M_{Rd}$       | 10,42  | kNm               |                                                                                      |
| Steel stress                                                                                                             | $\sigma_s$     | 158    | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                       |
| Maximum bar size                                                                                                         |                |        |                   |                                                                                      |
| Adapted maximum bar size, top                                                                                            | $\varphi'_s$   | 40     | mm                | EN 1992-1-1                                                                          |
|                                                                                                                          | $\varphi_s$    | 35     | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$ |
| Check $\varphi_s > \varphi_l$                                                                                            | 35             | mm     | >                 | 4 mm                                                                                 |
| Transversal direction                                                                                                    |                |        |                   |                                                                                      |

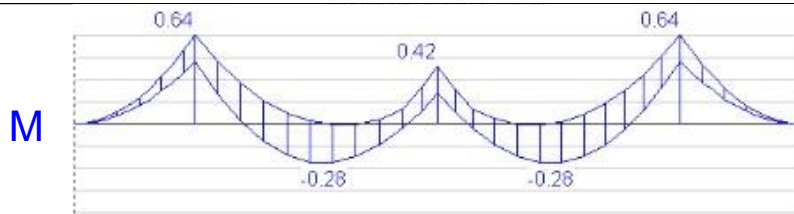


Figure K.66: Load distribution in transversal direction (frequent combination using Technosoft Liggers)

|                                         |              |          |                   |                                                                                                                                                                                 |
|-----------------------------------------|--------------|----------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bending moment SLS, top                 | $M_{Efreq}$  | 0,30     | kNm               |                                                                                                                                                                                 |
| Bending moment SLS, bottom              | $M_{Efreq}$  | 0,16     | kNm               |                                                                                                                                                                                 |
| Bending moment resistance, top          | $M_{Rd}$     | 0,85     | kNm               |                                                                                                                                                                                 |
| Bending moment resistance, bottom       | $M_{Rd}$     | 0,85     | kNm               |                                                                                                                                                                                 |
| Steel stress, top                       | $\sigma_s$   | 153      | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                  |
| Steel stress, bottom                    | $\sigma_s$   | 82       | N/mm <sup>2</sup> | $\sigma_s = \frac{M_{Efreq}}{M_{Rd}} * f_{yd}$                                                                                                                                  |
| Maximum bar size, top                   | $\varphi'_s$ | 41       | mm                | EN 1992-1-1                                                                                                                                                                     |
| Maximum bar size, bottom                | $\varphi'_s$ | 56       | mm                | EN 1992-1-1                                                                                                                                                                     |
| Adapted maximum bar size, top           | $\varphi_s$  | 8        | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                            |
| Adapted maximum bar size, bottom        | $\varphi_s$  | 11       | mm                | $\varphi_s = \varphi'_s * \frac{f_{ct,eff}}{2.9} * \frac{k_c * h_{cr}}{2 * (h - d)}$                                                                                            |
| Check $\varphi_s > \varphi_{t,t}$       | 8            | mm       | >                 | 4 mm                                                                                                                                                                            |
| Check $\varphi_s > \varphi_{t,b}$       | 11           | mm       | >                 | 4 mm                                                                                                                                                                            |
| <b>Deflection control</b>               |              |          |                   |                                                                                                                                                                                 |
| <b>Longitudinal direction</b>           |              |          |                   |                                                                                                                                                                                 |
| Reference reinforcement ratio           | $\rho_0$     | 0,005477 |                   | $\rho_0 = 10^{-3} * \sqrt{f_{ck}}$                                                                                                                                              |
| Tension reinforcement ratio             | $\rho_l$     | 0,003471 |                   | $\rho_l = \frac{A_{sl}}{A}$                                                                                                                                                     |
| Factor for different structural systems | K            | 1        |                   | EN 1992-1-1                                                                                                                                                                     |
| Compression reinforcement ratio         | $\rho'_l$    | 0        |                   |                                                                                                                                                                                 |
| Limit span/depth                        | $l/d$        | 321      |                   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_l} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_l} - 1 \right)^{3/2} \right] \text{ if } \rho_l \leq \rho_0$ |
| Corrective value for slenderness        |              | 1,97     |                   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Adapted span/depth limit                |              | 62       |                   |                                                                                                                                                                                 |



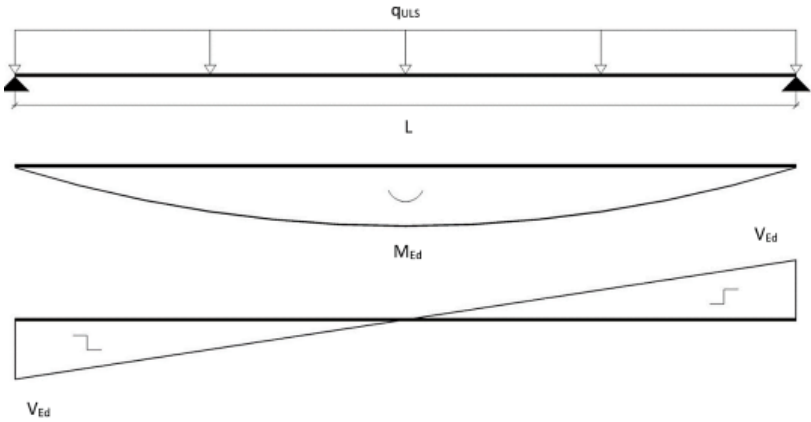
|                                          |              |          |   |                                                                                                                                                                                 |
|------------------------------------------|--------------|----------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Check                                    | l/h          | 16       | < | 62                                                                                                                                                                              |
| <b>Transversal direction</b>             |              |          |   |                                                                                                                                                                                 |
| Tension reinforcement ratio, top         | $\rho_{t,t}$ | 0,003696 |   | $\rho_{t,t} = \frac{A_{st,t}}{A}$                                                                                                                                               |
| Tension reinforcement ratio, bottom      | $\rho_{t,b}$ | 0,003696 |   | $\rho_{t,b} = \frac{A_{st,b}}{A}$                                                                                                                                               |
| Factor for different structural systems  | K            | 1,5      |   | EN 1992-1-1                                                                                                                                                                     |
| Compression reinforcement ratio          | $\rho'_l$    | 0        |   |                                                                                                                                                                                 |
| Limit span/depth, top                    | l/d          | 44       |   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
| Limit span/depth, bottom                 | l/d          | 44       |   | $\frac{l}{d} = K \left[ 11 + 1.5 \sqrt{f_{ck}} \frac{\rho_0}{\rho_t} + 3.2 \sqrt{f_{ck}} \left( \frac{\rho_0}{\rho_t} - 1 \right)^{3/2} \right] \text{ if } \rho_t \leq \rho_0$ |
| Corrective value for slenderness, top    |              | 2,02     |   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Corrective value for slenderness, bottom |              | 3,79     |   | $\frac{310}{\sigma_s}$                                                                                                                                                          |
| Check, top                               | l/h          | 26       | < | 88                                                                                                                                                                              |
| Check, bottom                            | l/h          | 26       | < | 165                                                                                                                                                                             |

### K.5.6 Detailing reinforcement requirements

| Minimum longitudinal tension reinforcement |               |         |                 |                                                      |
|--------------------------------------------|---------------|---------|-----------------|------------------------------------------------------|
| Section Modulus                            | W             | 1114341 | mm <sup>3</sup> |                                                      |
| Minimum principal reinforcement area (1)   | $A_{s,min,1}$ | 1250916 | mm <sup>2</sup> | $A_{s,min,1} = \frac{f_{ctm} * W}{f_{yd} * 0.9 * d}$ |
| Required reinforcement area for ULS        | $A_s$         | 104     | mm <sup>2</sup> | $A_s = \frac{M_{Ed}}{f_{yd} * 0.9 * d}$              |
| Minimum principal reinforcement area (2)   | $A_{s,min,2}$ | 130     | mm <sup>2</sup> | $A_{s,min,2} = 1.25 A_s$                             |
| Minimum principal reinforcement area       | $A_{s,min}$   | 130     | mm <sup>2</sup> | $A_{s,min} = \min[A_{s,min,1}; A_{s,min,2}]$         |
| Maximum reinforcement area                 |               |         |                 |                                                      |
| Longitudinal direction                     |               |         |                 |                                                      |
| Cross-sectional area of concrete           | $A_c$         | 39824   | mm <sup>2</sup> | $A_c = b_{eff} * h_s + b_r * h_r$                    |
| Maximum reinforcement area                 | $A_{s,max}$   | 1593    | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |

|                                                                     |                     |                 |                 |                                                      |
|---------------------------------------------------------------------|---------------------|-----------------|-----------------|------------------------------------------------------|
|                                                                     |                     |                 |                 |                                                      |
| <b>Transversal direction</b>                                        |                     |                 |                 |                                                      |
| Cross-sectional area of concrete                                    | $A_c$               | 34000           | mm <sup>2</sup> | $A_c = h_s * [1\text{ m}]$                           |
| Maximum reinforcement area                                          | $A_{s,max}$         | 1360            | mm <sup>2</sup> | $A_{s,max} = 0.04 * A_c$                             |
| <b>Maximum reinforcement spacing</b>                                |                     |                 |                 |                                                      |
| Minimum reinforcement spacing (1) longitudinal reinforcement        | $k_1$               | 1               |                 |                                                      |
| Minimum reinforcement spacing (1) transversal reinforcement, top    | $s_{min,1,l}$       | 4               | mm              | $s_{min,1} = k_1 * \varphi_l$                        |
| Minimum reinforcement spacing (1) transversal reinforcement, bottom | $s_{min,1,t,t}$     | 4               | mm              | $s_{min,1} = k_1 * \varphi_{t,t}$                    |
|                                                                     | $s_{min,1,t,b}$     | 4               | mm              | $s_{min,1} = k_1 * \varphi_{t,b}$                    |
| Maximum size of aggregate                                           | $d_g$               | 16              | mm              | Assumption                                           |
|                                                                     | $k_2$               | 5               |                 | EN 1992-1-1/NB                                       |
| Minimum reinforcement spacing (2)                                   | $s_{min,2}$         | 21              | mm              | $s_{min,2} = d_g + k_2$                              |
| Minimum reinforcement spacing longitudinal reinforcement            | $s_{min,l}$         | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20\text{ mm}]$ |
| Minimum reinforcement spacing transversal reinforcement, top        | $s_{min,t,t}$       | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20\text{ mm}]$ |
| Minimum reinforcement spacing transversal reinforcement, bottom     | $s_{min,t,b}$       | 21              | mm              | $s_{min} = \max[s_{min,1}; s_{min,2}; 20\text{ mm}]$ |
| <b>Maximum reinforcement spacing</b>                                |                     |                 |                 |                                                      |
| Maximum reinforcement spacing for principal reinforcement           | $s_{max,principal}$ | 250             | mm              | $s_{max,principal} = 2 * h_t \leq 250\text{ mm}$     |
| Maximum reinforcement spacing for secondary reinforcement           | $s_{max,secondary}$ | 102             | mm              | $s_{max,secondary} = 3 * h_s \leq 400\text{ mm}$     |
| <b>Check</b>                                                        |                     |                 |                 |                                                      |
| <b>Longitudinal reinforcement</b>                                   |                     |                 |                 |                                                      |
| Area of rebar                                                       | 130                 | mm <sup>2</sup> | < 138           | mm <sup>2</sup> < 1593                               |
| Spacing of rebar                                                    | 21                  | mm              | < 54            | mm < 250                                             |
| <b>Transversal reinforcement</b>                                    |                     |                 |                 |                                                      |
| Area of rebar top                                                   | 47                  | mm <sup>2</sup> | < 126           | mm <sup>2</sup> < 1360                               |
| Spacing of rebar top                                                | 21                  | mm              | < 100           | mm < 102                                             |
| Area of rebar bottom                                                | 47                  | mm <sup>2</sup> | < 126           | mm <sup>2</sup> < 1360                               |
| Spacing of rebar bottom                                             | 21                  | mm              | < 100           | mm < 102                                             |

### K.5.7 Rib openings

| Input                                                                                                                                                    |             |       |                 |                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------|-----------------|-------------------------------------------------|
| Height slab                                                                                                                                              | $h_s$       | 34    | mm              |                                                 |
| Height rib                                                                                                                                               | $h_r$       | 22,5  | mm              | $h_{r,o} = \frac{h_r - 125}{2}$                 |
| Total height                                                                                                                                             | $h_t$       | 56,5  | mm              | $h_t = h_s + h_{r,o}$                           |
|                                                                                                                                                          |             |       |                 |                                                 |
| Nominal cover                                                                                                                                            | $c_{nom}$   | 15    | mm              |                                                 |
|                                                                                                                                                          |             |       |                 |                                                 |
| Diameter longitudinal reinforcement                                                                                                                      | $\varphi_l$ | 4     | mm              |                                                 |
| Number of longitudinal reinforcement bars                                                                                                                | $n$         | 11    |                 |                                                 |
| Surface area longitudinal reinforcement                                                                                                                  | $A_{sl}$    | 138   | mm <sup>2</sup> | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$      |
| Spacing of longitudinal reinforcement                                                                                                                    | $s_l$       | 54    | mm              | $s_l = \frac{b_r}{n}$                           |
| Diameter stirrups                                                                                                                                        | $\varphi_s$ | 6     | mm              |                                                 |
| Surface area stirrups                                                                                                                                    | $A_{sw}$    | 28,27 | mm <sup>2</sup> | $A_{sw} = n * \frac{1}{4} \pi \varphi_s^2$      |
| Effective height of the cross-section                                                                                                                    | $d_l$       | 33,5  | mm              | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$ |
|                                                                                                                                                          |             |       |                 |                                                 |
| Load distribution                                                                                                                                        |             |       |                 |                                                 |
|  <p>Figure K.67: Load distribution in the longitudinal direction</p> |             |       |                 |                                                 |
| Maximum acting bending moment                                                                                                                            | $M_{Ed}$    | 1,18  | kNm             | See unity check longitudinal bending moment     |
| Maximum acting shear force                                                                                                                               | $V_{Ed}$    | 9,21  | kN              | $V_{Ed} = \frac{1}{2} q'l$                      |
|                                                                                                                                                          |             |       |                 |                                                 |
| Bending moment reinforcement                                                                                                                             |             |       |                 |                                                 |

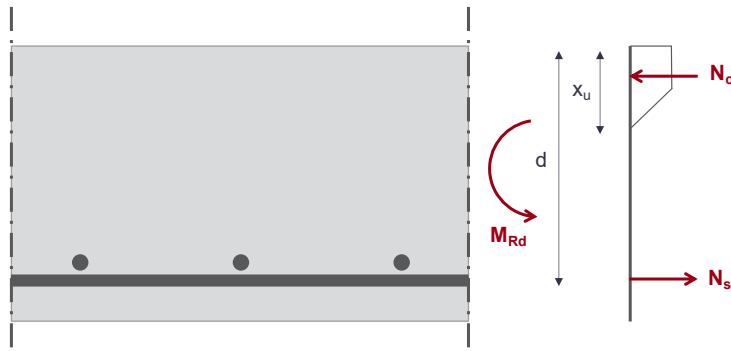


Figure K.68: Concrete cross-section

|                                                                                  |               |         |                   |                                                                                                          |
|----------------------------------------------------------------------------------|---------------|---------|-------------------|----------------------------------------------------------------------------------------------------------|
| Rebar tensile force                                                              | $N_s$         | 60100   | N                 | $N_s = A_{sl} * f_{yd}$                                                                                  |
| Concrete compressive force                                                       | $N_c$         |         | N                 | $N_c = \frac{3}{4} * x_u * f_{cd} * b_{eff}$                                                             |
| Concrete compressive zone height                                                 | $x_u$         | 34,84   | mm                | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * b_{eff}}$                             |
| Bending moment resistance                                                        | $M_{Rd}$      | 1196722 | Nmm               | $M_{Rd} = N_s * (d - 0.39x_u)$                                                                           |
|                                                                                  |               | 1,20    | kNm               |                                                                                                          |
| Unity Check                                                                      | 0,99          | ≤       | 1,0               |                                                                                                          |
| Distance from the end of the beam where the opening can be located               | x             | 0,133   | m                 | $\frac{qlx}{2} - \frac{qx^2}{2} - M_{Ed} = 0$                                                            |
| <b>Shear reinforcement</b>                                                       |               |         |                   |                                                                                                          |
| <b>Minimal reinforcement</b>                                                     |               |         |                   |                                                                                                          |
|                                                                                  | k             | 2,0     |                   | $k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$                                                                  |
| Smallest width of the cross-section in the tensile area                          | $b_w$         | 115     | mm                |                                                                                                          |
| Reinforcement ratio for longitudinal reinforcement                               | $\rho_l$      | 0,036   |                   | $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$                                                                |
|                                                                                  | $C_{Rd,c}$    | 0,12    |                   | EN 1992-1-1/NB                                                                                           |
|                                                                                  | $v_{min}$     | 0,30    | N/mm <sup>2</sup> | $v_{min} = 0.035 * k^{\frac{2}{3}} * f_{ck}^{\frac{1}{2}}$                                               |
|                                                                                  | $V_{Rd,c}$    | 4398    | N                 | $V_{Rd,c} = C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{\frac{1}{3}} * b_w$<br>$* d \leq v_{min} * b_w * d)$ |
|                                                                                  |               | 4       | kN                |                                                                                                          |
| Unity Check                                                                      | 2,09          | ≤       | 1,0               | Shear reinforcement required at the openings                                                             |
| <b>Maximum resistance</b>                                                        |               |         |                   |                                                                                                          |
| Coefficient taking into account the state of the stress in the compression chord | $\alpha_{cw}$ | 1       |                   | EN 1992-1-1/NB                                                                                           |
| Strength reduction factor for concrete cracked in shear                          | $v_1$         | 0,6     |                   | EN 1992-1-1/NB                                                                                           |

|                                     |              |         |                     |                                                                                     |
|-------------------------------------|--------------|---------|---------------------|-------------------------------------------------------------------------------------|
| Angle of the inclined struts        | $\theta$     | 45      | °                   | Assumption                                                                          |
| Limit value for shear resistance    | $V_{Rd,max}$ | 20803,5 | N                   | $V_{Rd,max} = \alpha_{cw} * b_w * z * v_1 * f_{cd} / (\cot(\theta) + \tan(\theta))$ |
|                                     |              | 21      | kN                  |                                                                                     |
| Unity Check                         | 0,44         | ≤       | 1,0                 |                                                                                     |
| <b>Required shear reinforcement</b> |              |         |                     |                                                                                     |
|                                     | $A_{sw}/s_w$ | 0,70    | mm <sup>2</sup> /mm | $\frac{A_{sw}}{s_w} = \frac{V_{Ed} * \tan(\theta)}{z * f_{yd}}$                     |
| Spacing of stirrups                 | $s_w$        | 40,25   | mm                  |                                                                                     |

### K.5.8 Check of manual calculations

The previous calculations are manual calculations done using Microsoft Excel. To ensure the accuracy of these calculations, a number of the manually calculated values are checked using Technosoft Construct. The results of the manual calculations and the Technosoft output for the bending moment resistances are in the same order of magnitude and therefore correspond sufficiently.

There is a discrepancy between the manual calculation and the Technosoft output for the shear force that can be taken by the concrete of the cross-section ( $V_{Rd,c}$ ). In the Technosoft calculation of this shear resistance, the effective height of the cross-section ( $d$ ) has a lower value than in the manual calculations. In the Technosoft calculations, a diameter for shear reinforcement is taken into consideration in the determination of the effective height. In the manual calculation of the effective height, this diameter is taken as zero.

| Bending moment resistance – Longitudinal direction |          |      |     |
|----------------------------------------------------|----------|------|-----|
| Manual calculation                                 | $M_{Rd}$ | 7,60 | kNm |
| Technosoft output                                  | $M_{Rd}$ | 10,6 | kNm |

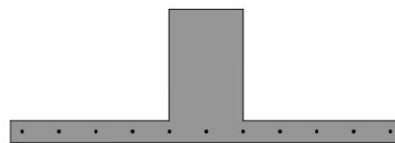
### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                           |
|---------------------------|-------------------------------------------|
| Elementtype               | : Balk                                    |
| Betonkwaliteit            | : C30/37                                  |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram       |
| Doorsnedeform             | : T2                                      |
| Afmetingen                | : b=596 h=204 b1=241 h1=170 b2=241 h2=170 |
| Scheurvorming volgens art | : 7.3.4                                   |
| Referentieperiode         | : 50 jaar                                 |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalige inklemming      | : nee                                  |

|                     |         |       |
|---------------------|---------|-------|
| Toegepaste wapening | : Boven | Onder |
| Breedte stortstleuf | : 0x12  | 11x4  |
|                     | : 50    |       |

#### Betondekking

|                                 |                 |               |
|---------------------------------|-----------------|---------------|
| Milieu                          | : Boven         | Onder         |
|                                 | : XC1           | : XC1         |
| Gestort tegen bestaand beton    | : Nee           | Nee           |
| Element met plaatgeometrie      | : Nee           | Nee           |
| Specifieke kwaliteitsbeheersing | : Nee           | Nee           |
| Oneffen beton oppervlak         | : Nee           | Nee           |
| Ondergrond                      | : Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse               | : S3            | S3            |
| Grootste korrel                 | : 16.0          |               |

|                                            |             |           |
|--------------------------------------------|-------------|-----------|
| Hoofdwapening                              | : 1ste laag | 1ste laag |
| Nominale dekking                           | : 17        | 15        |
| Toegepaste dekking                         | : 17        | 15        |
| Gelijkwaardige diameter                    | : 12        | 4         |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 12 10 0   | 4 10 0    |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 12 5 17   | 10 5 15   |

#### BELASTING

#### RESULTATEN

| Nr | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | Sterkte<br>$M_{Rd}$<br>[kNm] | $M_{Rd}$<br>[kNm] | Scheurvorming<br>$M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | Opm. |
|----|------------------|-------------------|----------------------|-----------------------|------------------------------|-------------------|----------------------------------------|-----------------------|------|
| 1  | 0.0              | -7.6              | 0.0                  | 0.0                   | 0.7                          | -10.6             | 0.0                                    | -12.0                 |      |

Figure K.69: Output Technosoft Construct Bending reinforcement in the longitudinal direction

### Bending moment resistance – Transversal direction

|                           |            |      |     |
|---------------------------|------------|------|-----|
| Manual calculation top    | $M_{Rd,t}$ | 0,85 | kNm |
| Manual calculation bottom | $M_{Rd,b}$ | 0,85 | kNm |
| Technosoft output top     | $M_{Rd,t}$ | 0,9  | kNm |
| Technosoft output bottom  | $M_{Rd,b}$ | 0,9  | kNm |

**Toegepaste normen volgens Eurocode met Nederlandse NB**

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

**Controle hoofdwapening. (B)****GEOMETRIE**

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=34                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |

**WAPENING**

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalige inklemming      | : nee                                  |
| Toegepaste wapening       | : Boven 10x4 Onder 0x4                 |
| Breedte stort sleuf       | : 50                                   |

**Betondekking**

|                                 |                               |
|---------------------------------|-------------------------------|
| Milieu                          | : Boven XC1 Onder XC1         |
| Gestort tegen bestaand beton    | : Nee Nee                     |
| Element met plaatgeometrie      | : Nee Nee                     |
| Specifieke kwaliteitsbeheersing | : Nee Nee                     |
| Oneffen beton oppervlak         | : Nee Nee                     |
| Ondergrond                      | : Glad / N.v.t. Glad / N.v.t. |
| Constructieklasse               | : S3 S3                       |
| Grootste korrel                 | : 16.0                        |

|                                            |                       |
|--------------------------------------------|-----------------------|
| Hoofdwapening                              | : 1ste laag 1ste laag |
| Nominale dekking                           | : 15 15               |
| Toegepaste dekking                         | : 15 15               |
| Gelijkwaardige diameter                    | : 4 4                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 4 10 0 4 10 0       |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 10 5 15 10 5 15     |

**BELASTING****RESULTATEN**

| Nr | Sterkte          |                   | Scheurvorming         |                       | Opm. |
|----|------------------|-------------------|-----------------------|-----------------------|------|
|    | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] |      |
| 1  | 0.0              | -0.6              | 0.0                   | -0.0                  | 11   |

Figure K.70: Output Technosoft Construct Bending reinforcement in transversal direction top



### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Controle hoofdwapening. (B)

#### GEOMETRIE

|                           |                                     |
|---------------------------|-------------------------------------|
| Elementtype               | : Balk                              |
| Betonkwaliteit            | : C30/37                            |
| Soort spanningsrekdiagram | : Parabolisch - rechthoekig diagram |
| Doorsnede vorm            | : Rechthoek                         |
| Afmetingen                | : b=1000 h=34                       |
| Scheurvorming volgens art | : 7.3.4                             |
| Referentieperiode         | : 50 jaar                           |



#### WAPENING

|                           |                                        |
|---------------------------|----------------------------------------|
| Staalkwaliteit            | : B500B                                |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |
| Beugeldiameter            | : 0                                    |
| Toevalige inklemming      | : nee                                  |
| Toegepaste wapening       | : Boven 0x4 Onder 10x4                 |
| Breedte stort sleuf       | : 50                                   |

#### Betondekking

|                                 |                               |
|---------------------------------|-------------------------------|
| Milieu                          | : Boven XC1 Onder XC1         |
| Gestort tegen bestaand beton    | : Nee Nee                     |
| Element met plaatgeometrie      | : Nee Nee                     |
| Specifieke kwaliteitsbeheersing | : Nee Nee                     |
| Oneffen beton oppervlak         | : Nee Nee                     |
| Ondergrond                      | : Glad / N.v.t. Glad / N.v.t. |
| Constructieklasse               | : S3 S3                       |
| Grootste korrel                 | : 16.0                        |

|                                            |                       |
|--------------------------------------------|-----------------------|
| Hoofdwapening                              | : 1ste laag 1ste laag |
| Nominale dekking                           | : 15 15               |
| Toegepaste dekking                         | : 15 15               |
| Gelijkwaardige diameter                    | : 4 4                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : 4 10 0 4 10 0       |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : 10 5 15 10 5 15     |

#### BELASTING

#### RESULTATEN

| Nr | Sterkte          |                   |                      |                       | Scheurvorming         |                       | Opm.         |
|----|------------------|-------------------|----------------------|-----------------------|-----------------------|-----------------------|--------------|
|    | $N_{Ed}$<br>[kN] | $M_{Ed}$<br>[kNm] | $N_{E,freq}$<br>[kN] | $M_{E,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] | $M_{R,freq}$<br>[kNm] |              |
| 1  | 0.0              | -0.3              | 0.0                  | 0.0                   | 0.4                   | -0.9                  | 0.0 -0.0 167 |

Figure K.71: Output Technosoft Construct Bending reinforcement in transversal direction top

## Shear force resistance – Longitudinal direction

|                    |            |       |    |
|--------------------|------------|-------|----|
| Manual calculation | $V_{Rd,c}$ | 20,21 | kN |
| Technosoft output  | $V_{Rd,c}$ | 14,52 | kN |

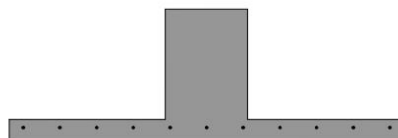
### Toegepaste normen volgens Eurocode met Nederlandse NB

|             |                          |                |             |
|-------------|--------------------------|----------------|-------------|
| Belastingen | NEN-EN 1990:2002         | C2:2010        | NB:2011(nl) |
|             | NEN-EN 1991-1-1:2002     | C1:2009        | NB:2011(nl) |
| Beton       | NEN-EN 1992-1-1:2011(nl) | C2/A1:2015(nl) | NB:2016(nl) |

### Dwarskracht en wringing. (B)

#### GEOMETRIE

|                           |                                           |
|---------------------------|-------------------------------------------|
| Elementtype               | : Balk                                    |
| Betonkwaliteit            | : C30/37                                  |
| Soort spanningsrekdiagram | : Parabolisch – rechthoekig diagram       |
| Doorsnede vorm            | : T2                                      |
| Afmetingen                | : b=607 h=204 b1=240 h1=170 b2=240 h2=170 |
| Referentieperiode         | : 50 jaar                                 |



#### WAPENING

|                           |                                        |       |       |
|---------------------------|----------------------------------------|-------|-------|
| Staalkwaliteit            | : B500B                                |       |       |
| Soort spanningsrekdiagram | : Bi-lineair diagram met klimmende tak |       |       |
| Toevallige inklemming     | : nee                                  |       |       |
|                           |                                        | Boven | Onder |
| Toegepaste wapening       | :                                      | 0x6   | 11x4  |
| Breedte stort sleuf       | :                                      | 50    |       |

#### Betondekking

|                                            |   |               |               |
|--------------------------------------------|---|---------------|---------------|
| Milieu                                     | : | Boven         | Onder         |
|                                            | : | XC1           | XC1           |
| Gestort tegen bestaand beton               | : | Nee           | Nee           |
| Element met plaatgeometrie                 | : | Nee           | Nee           |
| Specifieke kwaliteitsbeheersing            | : | Nee           | Nee           |
| Ongeeffen beton oppervlak                  | : | Nee           | Nee           |
| Ondergrond                                 | : | Glad / N.v.t. | Glad / N.v.t. |
| Constructieklasse                          | : | S3            | S3            |
| Grootste korrel                            | : | 16.0          |               |
| Hoofdwapening                              | : | 2de laag      | 2de laag      |
| Nominale dekking                           | : | 15            | 15            |
| Toegepaste dekking                         | : | 20            | 20            |
| Gelijkwaardige diameter                    | : | 6             | 4             |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | : | 6 10 0        | 4 10 0        |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | : | 10 5 15       | 10 5 15       |

|                                            |                        |           |                                   |
|--------------------------------------------|------------------------|-----------|-----------------------------------|
| Beugel / Verdeelwapening                   | :                      | 1ste laag | 1ste laag                         |
| Nominale dekking                           | :                      | 15        | 15                                |
| Toegepaste dekking                         | :                      | 15        | 15                                |
| Gelijkwaardige diameter                    | :                      | 5         | 5                                 |
| $C_{min,b}$ $C_{min,dur}$ $\Delta C_{dur}$ | :                      | 5 10 0    | 5 10 0                            |
| $C_{min}$ $\Delta C_{dev}$ $C_{nom}$       | :                      | 10 5 15   | 10 5 15                           |
| Minimale beugelafstand                     | :                      | 50        | Theta [graden] : 21.8             |
| Uitg.p. inw.hefboomsarm z                  | :                      | 0,9*d     |                                   |
| <b>BELASTING</b>                           |                        |           |                                   |
| NEd                                        | [kN] :                 | 0.0       | MEd [kNm] : 0.0                   |
| VEd                                        | [kN] :                 | 9.2       | TEd [kNm] : 0.0                   |
| Q-permanent                                | [kN/m] :               | 0.0       | Veiligheidsklasse : 1             |
| Q-veranderlijk                             | [kN/m] :               | 0.0       | Gamma-permanent : 1.08            |
| L                                          | [m] :                  | 3.3       | Gamma-veranderlijk : 1.35         |
|                                            |                        |           | X [m] : 0.0                       |
| <b>RESULTATEN</b>                          |                        |           |                                   |
| Beugeldiameter                             | [mm] :                 | 5         | z [mm] : 163.80                   |
| Trekzijde                                  | :                      | Onder     | Wapeningsverhouding : 0.00125     |
| Dwarskracht                                |                        |           | Wringing                          |
| $V_{Rd,max}$                               | [kN] :                 | 75.75     | $T_{Rd,max}$ [kNm] : 4.13         |
| $V_{Ed}$                                   | [kN] :                 | 9.21      | $T_{Ed}$ [kNm] : 0.00             |
| $V_{Rd,c}$                                 | [kN] :                 | 14.52     | $T_{Rd,c}$ [kNm] : 1.53           |
| A-opg                                      | [mm <sup>2</sup> /m] : | 0.00      | A-langs [mm <sup>2</sup> ] : 0.00 |
| A-bgl                                      | [mm <sup>2</sup> /m] : | 0.00      | A-bgl [mm <sup>2</sup> /m] : 0.00 |
| H.o.h. afstand                             | [mm] :                 | 300.0     | Aant. beugelsneden/drsn: 1        |

Figure K.72: Output Technosoft Construct shear reinforcement in the longitudinal direction

### K.5.9 Steel beam



Figure K.73: Schematisation of the load distribution on the steel beam

The spread-out point loads from the ribs on the steel beam are schematised as a distributed load, as shown in Figure K.73. The load on the beam include the own weight of the beam and the weight of the floor elements on both sides of the beam.

| Input                   |            |          |                 |                          |
|-------------------------|------------|----------|-----------------|--------------------------|
| Dimensions              |            |          |                 |                          |
| Number of ribs          | n          | 7        |                 |                          |
| Span                    | L          | 6100     | mm              |                          |
| Profile properties      |            |          |                 |                          |
| RHS 200x100 / 8         |            |          |                 | (Eurocode Applied, n.d.) |
| Height                  | h          | 200      | mm              |                          |
| Width                   | b          | 120      | mm              |                          |
| Wall thickness          | t          | 8        | mm              |                          |
| Outer rounding radius   | r          | 12       | mm              |                          |
| Area                    | A          | 4795     | mm <sup>2</sup> |                          |
| Second moment of area   | $I_y$      | 25290000 | mm <sup>4</sup> |                          |
| Plastic section modulus | $W_{y,pl}$ | 252900   | mm <sup>3</sup> |                          |
| Weight                  | G          | 312700   | kg/m            |                          |
|                         |            | 0,37     | kN/m            |                          |
| Section classification  | Class      | 1        |                 |                          |

|                                       |               |           |                   |                                                     |
|---------------------------------------|---------------|-----------|-------------------|-----------------------------------------------------|
|                                       |               |           |                   |                                                     |
| <b>Steel properties</b>               |               |           |                   |                                                     |
| <b>S355</b>                           |               |           |                   |                                                     |
| Design yield stress                   | $f_y$         | 355       | N/mm <sup>2</sup> |                                                     |
| Young's modulus                       | E             | 210000    | N/mm <sup>2</sup> |                                                     |
|                                       |               |           |                   |                                                     |
| Partial factor                        | $\gamma_{M0}$ | 1,0       |                   |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Loads</b>                          |               |           |                   |                                                     |
| Load from floor element on beam (ULS) | $V_{ULS}$     | 9,21      | kN                |                                                     |
| Load from floor element on beam (SLS) | $V_{SLS}$     | 4,58      | kN                |                                                     |
|                                       |               |           |                   |                                                     |
| Distributed load (ULS)                | $q_{ULS}$     | 21,51     | kN/m              | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$           |
| Distributed load (SLS)                | $q_{SLS}$     | 10,88     | kN/m              | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$           |
|                                       |               |           |                   |                                                     |
| <b>Load distribution</b>              |               |           |                   |                                                     |
| Bending moment                        | $M_{Ed}$      | 100,0     | kNm               | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$                  |
| Shear force                           | $V_{Ed}$      | 65,6      | kN                | $V_{Ed} = \frac{1}{2} q_{ULS} L$                    |
|                                       |               |           |                   |                                                     |
| <b>Bending resistance</b>             |               |           |                   |                                                     |
| Bending moment resistance             | $M_{Rd}$      | 111008500 | Nmm               | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$         |
|                                       |               | 111       | kNm               |                                                     |
|                                       |               |           |                   |                                                     |
| Unity check                           | 0,90          | ≤         | 1,0               |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Shear resistance</b>               |               |           |                   |                                                     |
| Shear area                            | $A_v$         | 2996,875  | mm <sup>2</sup>   | $A_v = \frac{A * h}{b + h}$                         |
|                                       |               |           |                   |                                                     |
| Shear force resistance                | $V_{Rd}$      | 614238    | N                 | $V_{Rd} = \frac{A_v (f_y / \sqrt{3})}{\gamma_{M0}}$ |
|                                       |               | 614       | kN                |                                                     |
|                                       |               |           |                   |                                                     |
| Unity check                           | 0,107         | ≤         | 1,0               |                                                     |
|                                       |               |           |                   |                                                     |
|                                       |               |           |                   |                                                     |
| <b>Deflection (SLS)</b>               |               |           |                   |                                                     |
| Maximum deflection                    | $w_{max}$     | 12,2      | mm                | $w_{max} = \frac{L}{500}$                           |
| Deflection                            | w             | 0,00      | mm                | $w = \frac{5}{384} * \frac{qL}{EI}$                 |
|                                       |               |           |                   |                                                     |
|                                       | 0             | mm        | ≤                 | 12,2 mm                                             |

## Input

| Dimensions                            |                   |           |                   |                                             |
|---------------------------------------|-------------------|-----------|-------------------|---------------------------------------------|
| Number of ribs                        | n                 | 7         |                   |                                             |
| Span                                  | L                 | 6100      | mm                |                                             |
|                                       |                   |           |                   |                                             |
| Profile properties                    |                   |           |                   |                                             |
| RHS 180x100 / 8                       |                   |           |                   | (Eurocode Applied, n.d.)                    |
| Height                                | h                 | 180       | mm                |                                             |
| Width                                 | b                 | 100       | mm                |                                             |
| Wall thickness                        | t                 | 10        | mm                |                                             |
| Outer rounding radius                 | r                 | 15        | mm                |                                             |
| Area                                  | A                 | 5093      | mm <sup>2</sup>   |                                             |
| Second moment of area                 | I <sub>y</sub>    | 20360000  | mm <sup>4</sup>   |                                             |
| Plastic section modulus               | W <sub>y,pl</sub> | 287900    | mm <sup>3</sup>   |                                             |
| Weight                                | G                 | 40        | kg/m              |                                             |
|                                       |                   | 0,39      | kN/m              |                                             |
| Section classification                | Class             | 1         |                   |                                             |
|                                       |                   |           |                   |                                             |
| Steel properties                      |                   |           |                   |                                             |
| S355                                  |                   |           |                   |                                             |
| Design yield stress                   | f <sub>y</sub>    | 355       | N/mm <sup>2</sup> |                                             |
| Young's modulus                       | E                 | 210000    | N/mm <sup>2</sup> |                                             |
|                                       |                   |           |                   |                                             |
| Partial factor                        | γ <sub>M0</sub>   | 1,0       |                   |                                             |
|                                       |                   |           |                   |                                             |
| Loads                                 |                   |           |                   |                                             |
| Load from floor element on beam (ULS) | V <sub>ULS</sub>  | 9,21      | kN                |                                             |
| Load from floor element on beam (SLS) | V <sub>SLS</sub>  | 4,58      | kN                |                                             |
|                                       |                   |           |                   |                                             |
| Distributed load (ULS)                | q <sub>ULS</sub>  | 21,53     | kN/m              | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$   |
| Distributed load (SLS)                | q <sub>SLS</sub>  | 10,90     | kN/m              | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$   |
|                                       |                   |           |                   |                                             |
| Load distribution                     |                   |           |                   |                                             |
| Bending moment                        | M <sub>Ed</sub>   | 100,1     | kNm               | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$          |
| Shear force                           | V <sub>Ed</sub>   | 65,7      | kN                | $V_{Ed} = \frac{1}{2} q_{ULS} L$            |
|                                       |                   |           |                   |                                             |
| Bending resistance                    |                   |           |                   |                                             |
| Bending moment resistance             | M <sub>Rd</sub>   | 102204500 | Nmm               | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$ |
|                                       |                   | 102       | kNm               |                                             |
|                                       |                   |           |                   |                                             |
| Unity check                           | 0,98              | ≤         | 1,0               |                                             |
|                                       |                   |           |                   |                                             |
| Shear resistance                      |                   |           |                   |                                             |
| Shear area                            | A <sub>v</sub>    | 3274      | mm <sup>2</sup>   | $A_v = \frac{A * h}{b + h}$                 |

|                         |           |        |     |                                                  |
|-------------------------|-----------|--------|-----|--------------------------------------------------|
| Shear force resistance  | $V_{Rd}$  | 671052 | N   | $V_{Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}}$ |
|                         |           | 671    | kN  |                                                  |
| Unity check             | 0,098     | ≤      | 1,0 |                                                  |
| <b>Deflection (SLS)</b> |           |        |     |                                                  |
| Maximum deflection      | $w_{max}$ | 12,2   | mm  | $w_{max} = \frac{L}{500}$                        |
| Deflection              | $w$       | 0,00   | mm  | $w = \frac{5}{384} * \frac{qL^4}{EI}$            |
|                         | 0         | mm     | ≤   | 12,2 mm                                          |

## K.6 Option B.ii: Prestressed short span with accessibility from the top

### K.6.1 Input

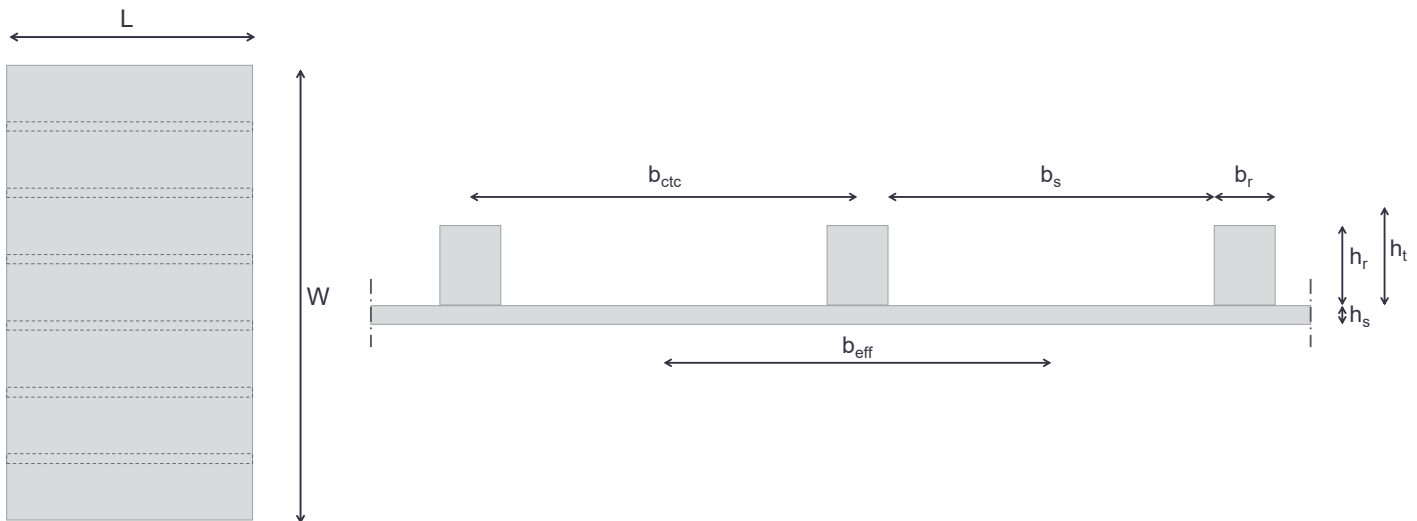


Figure K.74: Indication of the dimensions

| Dimensions              |           |      |    |                                                                                    |
|-------------------------|-----------|------|----|------------------------------------------------------------------------------------|
| Span                    | L         | 3300 | mm |                                                                                    |
| Width                   | W         | 6100 | mm |                                                                                    |
| Number of ribs          |           | 7    |    |                                                                                    |
| Height slab             | $h_s$     | 36   | mm | $\geq \max[\varphi_{t,t}; \varphi_{t,b}; \varphi_l; \varphi_p] + 2 * c_{nom} = 36$ |
| Height rib              | $h_r$     | 170  | mm | $\geq 170$ mm                                                                      |
| Height rib at opening   | $h_{r,o}$ | 22,5 | mm | $h_{r,o} = \frac{h_r - 125}{2}$                                                    |
| Total height            | $h_t$     | 206  | mm |                                                                                    |
| Total height at opening | $h_{t,o}$ | 58,5 | mm |                                                                                    |
|                         |           |      |    |                                                                                    |

|                                               |                  |        |                   |                                           |
|-----------------------------------------------|------------------|--------|-------------------|-------------------------------------------|
| Width rib                                     | $b_r$            | 100    | mm                |                                           |
| Space between ribs                            | $b_s$            | 771    | mm                | $\geq 170$ mm                             |
| Centre to centre distance between ribs        | $b_{ctc}$        | 871    | mm                | $b_{ctc} = b_r + b_s$                     |
| <b>Concrete properties</b>                    |                  |        |                   |                                           |
| C30/37                                        |                  |        |                   |                                           |
| Density                                       | $\rho_{rep}$     | 25     | kN/m <sup>3</sup> |                                           |
| Characteristic cylinder strength              | $f_{ck}$         | 30     | N/mm <sup>2</sup> |                                           |
| Partial safety factor concrete                | $\gamma_c$       | 1,5    |                   |                                           |
| Design compressive strength                   | $f_{cd}$         | 20     | N/mm <sup>2</sup> |                                           |
| Design tensile strength                       | $f_{ctd}$        | 1,35   | N/mm <sup>2</sup> |                                           |
| Mean tensile strength                         | $f_{ctm}$        | 2,9    | N/mm <sup>2</sup> |                                           |
| Young's modulus                               | $E_c$            | 33000  | N/mm <sup>2</sup> |                                           |
| <b>Reinforcement properties</b>               |                  |        |                   |                                           |
| <b>Longitudinal reinforcement</b>             |                  |        |                   |                                           |
| Diameter longitudinal reinforcement           | $\phi_l$         | 4      | mm                |                                           |
| Number of longitudinal reinforcement bars     | $n$              | 11     |                   |                                           |
| Surface area longitudinal reinforcement       | $A_{sl}$         | 138    | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \phi_l^2$   |
| Spacing of longitudinal reinforcement         | $s_l$            | 53     | mm                | $s_l = \frac{b_{eff}}{n}$                 |
| Effective height of the cross-section         | $d_l$            | 189    | mm                | $d = h - c - \phi_s - \frac{1}{2} \phi_l$ |
| <b>Concrete cover</b>                         |                  |        |                   |                                           |
| Minimum cover due to environmental conditions | $c_{min,dur}$    | 10     | mm                | XC1                                       |
| Minimum cover due to bond requirement         | $c_{min,b}$      | 4      | mm                | EN 1992-1-1                               |
| Minimum cover                                 | $c_{min}$        | 10     | mm                |                                           |
| Allowance in design for deviation             | $\Delta c_{dev}$ | 5      | mm                | EN 1992-1-1/NB                            |
| Nominal cover                                 | $c_{nom}$        | 15     | mm                |                                           |
| <b>Reinforcement steel</b>                    |                  |        |                   |                                           |
| B500 B                                        |                  |        |                   |                                           |
| Yield strength                                | $f_{yk}$         | 500    | N/mm <sup>2</sup> |                                           |
| Partial safety factor steel                   | $\gamma_s$       | 1,15   |                   |                                           |
| Design yield stress                           | $f_{yd}$         | 435    | N/mm <sup>2</sup> |                                           |
| Young's modulus                               | $E_s$            | 200000 | N/mm <sup>2</sup> |                                           |
| <b>Prestressing steel</b>                     |                  |        |                   |                                           |
| Y1770C                                        |                  |        |                   | EN 10138-2                                |
| Characterstic tensile strength                | $f_{pk}$         | 1770   | N/mm <sup>2</sup> |                                           |
| 0,1% proof-stress of prestressing steel       | $f_{p0,1k}$      | 1593   | N/mm <sup>2</sup> |                                           |



|                                  |             |     |                 |                                                                                         |
|----------------------------------|-------------|-----|-----------------|-----------------------------------------------------------------------------------------|
| Diameter of prestressing tendons | $\varphi_p$ | 6   | mm              |                                                                                         |
| Number of prestressing tendons   | n           | 7   |                 |                                                                                         |
| Area of prestressing steel       | $A_p$       | 198 | mm <sup>2</sup> | $A_p = n * \frac{1}{4} \pi \varphi_p^2$                                                 |
| Spacing of prestressing tendons  | $s_p$       | 83  | mm              | $s_p = \frac{b_{eff}}{n} \leq \max[d_g + 5; 2\varphi_p; 20 \text{ mm}] = 21 \text{ mm}$ |

### K.6.2 Loads

| Permanent loads                                     |                |      |                   |                                                                             |
|-----------------------------------------------------|----------------|------|-------------------|-----------------------------------------------------------------------------|
| Slab                                                | $g_{slab}$     | 0,85 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                               |
| Rib                                                 | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                |
| Ceiling panels                                      | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                             |
| Building services                                   | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                        |
|                                                     |                |      |                   |                                                                             |
| Total deadload longitudinal direction               | $g_{k,l}$      | 1,60 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$ |
|                                                     |                |      |                   |                                                                             |
| Variable load                                       |                |      |                   |                                                                             |
| Variable floor load residential buildings           | $q_{res}$      | 1,75 | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                              |
| Movable partitions                                  | $q_{part}$     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                 |
| Total variable floor load                           | $q_{tot}$      | 2,55 | kN/m <sup>2</sup> |                                                                             |
|                                                     |                |      |                   |                                                                             |
| Total variable floor load in longitudinal direction | $q_{k,l}$      | 2,22 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                               |
|                                                     |                |      |                   |                                                                             |
| Load combination ULS                                |                |      |                   |                                                                             |
| Partial factor for permanent loads                  | $\gamma_G$     | 1,35 |                   | EN 1990/NB                                                                  |
| Partial factor for variable loads                   | $\gamma_Q$     | 1,5  |                   | EN 1990/NB                                                                  |
| Partial factor for prestressing                     | $\gamma_P$     | 1,2  |                   | EN 1992-1-1/NB                                                              |
|                                                     |                |      |                   |                                                                             |
| ULS load combination in longitudinal direction      | $q_{ULS,l}$    | 5,50 | kN/m              | EN 1990 6.10a                                                               |
|                                                     |                |      |                   |                                                                             |
| Load combination SLS                                |                |      |                   |                                                                             |
| Factor for frequent value of a variable action      | $\psi_{1,1}$   | 0,5  |                   | EN 1990                                                                     |
|                                                     |                |      |                   |                                                                             |
| SLS load combination in longitudinal direction      | $q_{SLS,l}$    | 2,71 | kN/m              | EN 1990 6.15a                                                               |

### K.6.3 Preliminary partial prestressing calculations at the full cross-section

#### Choice of prestressing load

Chosen to remain uncracked under permanent load

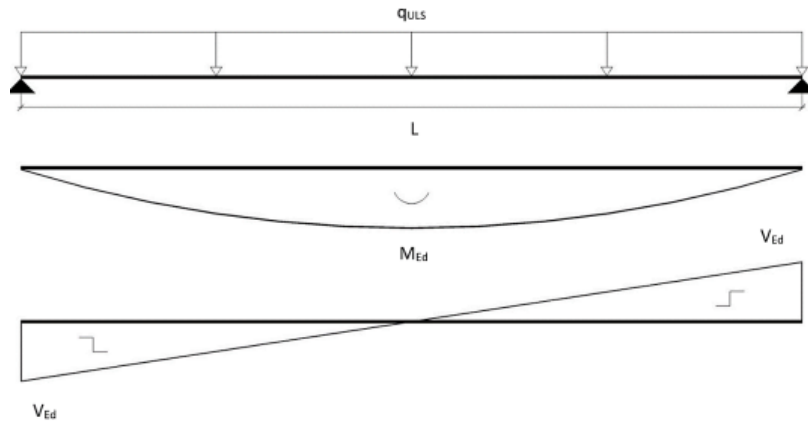


Figure K.75: Load distribution in the longitudinal direction

|                                                                  |       |   |     |                             |
|------------------------------------------------------------------|-------|---|-----|-----------------------------|
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 3 | kNm | $M_g = \frac{1}{8} q_g l^2$ |
|------------------------------------------------------------------|-------|---|-----|-----------------------------|

#### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                         |       |         |                 |                                                         |
|---------------------------------------------------------|-------|---------|-----------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction | $A_c$ | 38034   | mm <sup>2</sup> |                                                         |
| Distance of tendon to the centre of gravity             | $e_p$ | 43      | mm              | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                           | $W_t$ | 1006990 | mm <sup>3</sup> |                                                         |

$$\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$$

$$\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$$

|                             |                    |   |       |   |
|-----------------------------|--------------------|---|-------|---|
| Prestressing force required | $P_{m,\infty,req}$ | > | 43380 | N |
|-----------------------------|--------------------|---|-------|---|

|                                                                                                                                                   |     |  |  |                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----|--|--|--------------------------|
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be | 20% |  |  | (Walraven & Braam, 2019) |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----|--|--|--------------------------|

|                                     |               |       |   |                                      |
|-------------------------------------|---------------|-------|---|--------------------------------------|
| Initial prestressing force required | $P_{m,0,req}$ | 54225 | N | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$ |
|-------------------------------------|---------------|-------|---|--------------------------------------|

|  |       |      |  |                |
|--|-------|------|--|----------------|
|  | $k_7$ | 0,75 |  | EN 1992-1-1/NB |
|--|-------|------|--|----------------|

|  |       |      |  |                |
|--|-------|------|--|----------------|
|  | $k_8$ | 0,85 |  | EN 1992-1-1/NB |
|--|-------|------|--|----------------|

|                                   |                 |      |                   |                                                       |
|-----------------------------------|-----------------|------|-------------------|-------------------------------------------------------|
| Initial prestressing steel stress | $\sigma_{pm,0}$ | 1328 | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |
|-----------------------------------|-----------------|------|-------------------|-------------------------------------------------------|

|                                               |             |    |                 |                                             |
|-----------------------------------------------|-------------|----|-----------------|---------------------------------------------|
| Minimum required amount of prestressing steel | $A_{p,req}$ | 41 | mm <sup>2</sup> | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$ |
|-----------------------------------------------|-------------|----|-----------------|---------------------------------------------|

|                                     |                      |                 |                   |                                            |                 |
|-------------------------------------|----------------------|-----------------|-------------------|--------------------------------------------|-----------------|
| Amount of prestressing steel stress | 198                  | mm <sup>2</sup> | ≥                 | 41                                         | mm <sup>2</sup> |
| Prestressing steel stress           | $\sigma_{pm,\infty}$ | 1062            | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$ |                 |
| Working prestressing force          | $P_{m,\infty}$       | 210191          | N                 | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$  |                 |
| Initial prestressing force          | $P_{m,0}$            | 262739          | N                 | $P_{m,0} = \sigma_{pm,0} * A_p$            |                 |

#### Determination of the required amount of reinforcing steel

|                                                   |                   |          |                          |                                                  |
|---------------------------------------------------|-------------------|----------|--------------------------|--------------------------------------------------|
| Bending moment due to permanent and variable load | M <sub>g+q</sub>  | 8        | kNm                      | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$              |
| Bending moment due to prestressing                | M <sub>p</sub>    | 10899080 | Nmm                      | $M_p = \gamma_P * P_{m,\infty} * e_p$            |
|                                                   |                   | 11       | kNm                      |                                                  |
| Total bending moment                              | M <sub>tot</sub>  | -3       | kNm                      | $M_{tot} = M_{g+q} - M_p$                        |
|                                                   |                   |          |                          |                                                  |
| Time dependent losses are estimated to be         | 10%               |          | (Walraven & Braam, 2019) |                                                  |
| Friction loss is assumed to be                    | 10%               |          | (Walraven & Braam, 2019) |                                                  |
| Working prestressing steel stress                 | σ <sub>pm,∞</sub> | 1075     | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$ |
|                                                   |                   |          |                          |                                                  |

It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0.1k}$ )

|  |                |     |                   |                                  |  |
|--|----------------|-----|-------------------|----------------------------------|--|
|  | $\Delta\sigma$ | 518 | N/mm <sup>2</sup> | $f_{p0.1k} - \sigma_{pm,\infty}$ |  |
|--|----------------|-----|-------------------|----------------------------------|--|

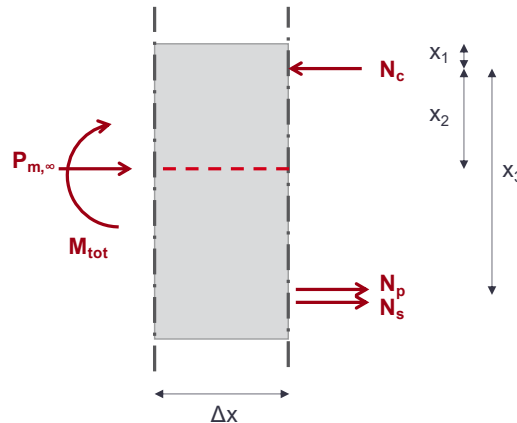


Figure K.76: Total bending moment around the resulting concrete compressive

|                             |                     |                                                                     |                 |                                                                                                                              |
|-----------------------------|---------------------|---------------------------------------------------------------------|-----------------|------------------------------------------------------------------------------------------------------------------------------|
|                             | x <sub>1</sub>      | 50                                                                  | mm              |                                                                                                                              |
|                             | x <sub>2</sub>      | 92                                                                  | mm              |                                                                                                                              |
|                             | x <sub>3</sub>      | 135                                                                 | mm              | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force          | N <sub>p</sub>      | 102468                                                              | N               | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force  | P <sub>m,∞</sub>    | 212819                                                              | N               | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force         | N <sub>s</sub>      | -247255                                                             | N               | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                             |                     |                                                                     |                 |                                                                                                                              |
| Required reinforcement area | A <sub>sl,req</sub> | -495                                                                | mm <sup>2</sup> | $N_s = f_{yk} * A_{sl}$                                                                                                      |
|                             |                     | A <sub>sl</sub> < 0 mm <sup>2</sup> : minimum reinforcement applies |                 |                                                                                                                              |
|                             |                     |                                                                     |                 |                                                                                                                              |

| Detailing of reinforcement                                   |                 |            |                   |                                                                                                                                                                                                            |
|--------------------------------------------------------------|-----------------|------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Minimum reinforcement is required                            |                 |            |                   |                                                                                                                                                                                                            |
|                                                              | $\alpha_e$      | 7          |                   | (Walraven & Braam, 2019)                                                                                                                                                                                   |
| Minimum reinforcement ratio                                  | $\rho_{min}$    | 0,6997%    |                   | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$                                                                                                                                                 |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Smallest width of the cross-section in the tensile area      | $b_w$           | 100        | mm                |                                                                                                                                                                                                            |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Applied reinforcement ratio                                  | $\rho$          | 0,731%     | $\leq \rho_{min}$ | $\rho_l = \frac{A_{sl}}{b_w d}$                                                                                                                                                                            |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Control of the crack width (SLS)                             |                 |            |                   |                                                                                                                                                                                                            |
| Maximum crack width                                          | $w_{max}$       | 30         | mm                | EN 1992-1-1/NB                                                                                                                                                                                             |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Ratio of bond strength of prestressing and reinforcing steel | $\xi$           | 0,70       |                   | EN 1992-1-1                                                                                                                                                                                                |
| Bonding factor of prestressing steel                         | $\xi_1$         | 0,68       |                   | $\xi_1 = \sqrt{\xi * \frac{\varphi_s}{\varphi_p}}$                                                                                                                                                         |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Bending moment due to permanent and variable load            | $M_{g+q}$       | 4          | kNm               | $M_{g+q} = \frac{1}{8} q_{SLS} l^2$                                                                                                                                                                        |
| Bending moment due to prestressing                           | $M_p$           | 9082566    | Nmm               | $M_p = P_{m,\infty} * e_p$                                                                                                                                                                                 |
|                                                              |                 | 9          | kNm               |                                                                                                                                                                                                            |
| Total bending moment                                         | $M_{tot}$       | -5         | kNm               | $M_{tot} = M_{g+q} - M_p$                                                                                                                                                                                  |
|                                                              |                 |            |                   |                                                                                                                                                                                                            |
| Strain in steel                                              | $\varepsilon_s$ | -0,0033687 |                   | $\sum M = 0$ $\Leftrightarrow \varepsilon_s (A_s + \xi_1 A_p) E_s * x_3 + P_{m,\infty} * x_2 = M_{tot}$ $\Leftrightarrow \varepsilon_s = \frac{M_{tot} - P_{m,\infty} * x_2}{(A_s + \xi_1 A_p) E_s * x_3}$ |
| The cross-section is not cracked in SLS                      |                 |            |                   |                                                                                                                                                                                                            |

#### K.6.4 Preliminary partial prestressing calculations at rib opening

##### Choice of prestressing load

Chosen to remain uncracked under permanent load

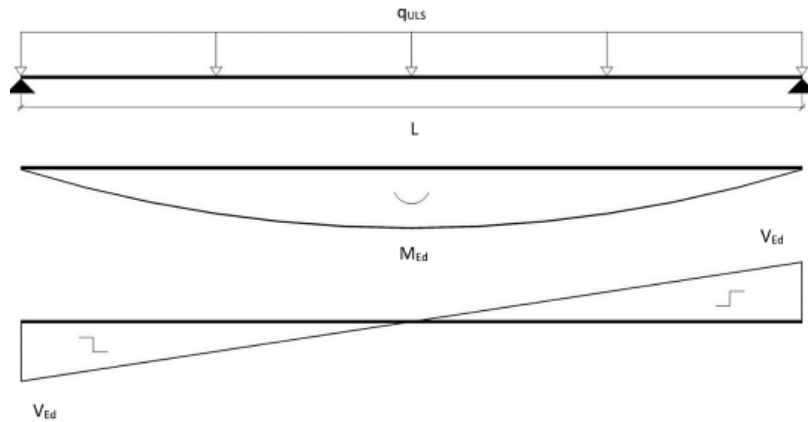


Figure K.77: Load distribution in the longitudinal direction

|                                                                  |       |     |     |                                  |
|------------------------------------------------------------------|-------|-----|-----|----------------------------------|
| Distance from the end of the beam that has a rib opening         | x     | 294 | mm  |                                  |
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 1,0 | kNm | $M(x) = \frac{q_g x}{2} (l - x)$ |

##### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                                                                                                                   |                                                                                                                                                                             |        |                   |                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-------------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction                                                                                           | $A_c$                                                                                                                                                                       | 23284  | mm <sup>2</sup>   |                                                         |
| Distance of tendon to the centre of gravity                                                                                                       | $e_p$                                                                                                                                                                       | 0      | mm                | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                                                                                                                     | $W_t$                                                                                                                                                                       | 108979 | mm <sup>3</sup>   |                                                         |
|                                                                                                                                                   | $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |        |                   |                                                         |
| Prestressing force required                                                                                                                       | $P_{m,\infty,req}$                                                                                                                                                          | >      | 209665            | N                                                       |
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be | 20%                                                                                                                                                                         |        |                   | (Walraven & Braam, 2019)                                |
| Initial prestressing force required                                                                                                               | $P_{m,0,req}$                                                                                                                                                               | 262081 | N                 | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                    |
|                                                                                                                                                   | $k_7$                                                                                                                                                                       | 0,75   |                   | EN 1992-1-1/NB                                          |
|                                                                                                                                                   | $k_8$                                                                                                                                                                       | 0,85   |                   | EN 1992-1-1/NB                                          |
| Initial prestressing steel stress                                                                                                                 | $\sigma_{pm,0}$                                                                                                                                                             | 1328   | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$   |
| Minimum required amount of prestressing steel                                                                                                     | $A_{p,req}$                                                                                                                                                                 | 197    | mm <sup>2</sup>   | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$             |

|                                                                                                                       |                      |                 |                          |                                                  |                 |
|-----------------------------------------------------------------------------------------------------------------------|----------------------|-----------------|--------------------------|--------------------------------------------------|-----------------|
| Amount of prestressing steel stress                                                                                   | 198                  | mm <sup>2</sup> | ≥                        | 197                                              | mm <sup>2</sup> |
| Prestressing steel stress                                                                                             | $\sigma_{pm,\infty}$ | 1062            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$       |                 |
| Working prestressing force                                                                                            | $P_{m,\infty}$       | 210191          | N                        | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$        |                 |
| Initial prestressing force                                                                                            | $P_{m,0}$            | 262739          | N                        | $P_{m,0} = \sigma_{pm,0} * A_p$                  |                 |
| Determination of the required amount of reinforcing steel                                                             |                      |                 |                          |                                                  |                 |
| Bending moment due to permanent and variable load                                                                     | $M_{g+q}$            | 2               | kNm                      | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$              |                 |
| Bending moment due to prestressing                                                                                    | $M_p$                | 0               | Nmm                      | $M_p = \gamma_P * P_{m,\infty} * e_p$            |                 |
|                                                                                                                       |                      | 0               | kNm                      |                                                  |                 |
| Total bending moment                                                                                                  | $M_{tot}$            | 2               | kNm                      | $M_{tot} = M_{g+q} - M_p$                        |                 |
|                                                                                                                       |                      |                 |                          |                                                  |                 |
| Time dependent losses are estimated to be                                                                             | 10%                  |                 | (Walraven & Braam, 2019) |                                                  |                 |
| Friction loss is assumed to be                                                                                        | 10%                  |                 | (Walraven & Braam, 2019) |                                                  |                 |
| Working prestressing steel stress                                                                                     | $\sigma_{pm,\infty}$ | 1075            | N/mm <sup>2</sup>        | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$ |                 |
| It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0,1k}$ ) |                      |                 |                          |                                                  |                 |
|                                                                                                                       | $\Delta\sigma$       | 518             | N/mm <sup>2</sup>        | $f_{p0,1k} - \sigma_{pm,\infty}$                 |                 |
|                                                                                                                       |                      |                 |                          |                                                  |                 |

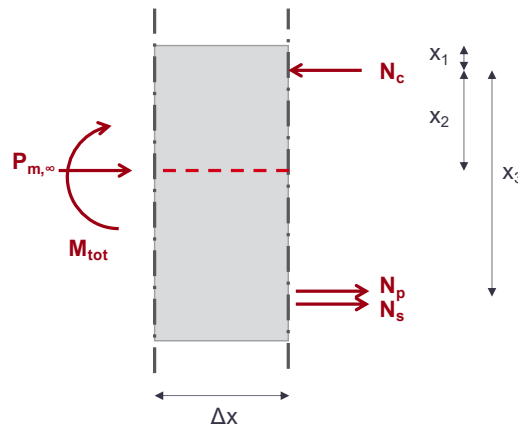


Figure K.78: Total bending moment around the resulting concrete compressive

|                                                              |                |         |                 |                                                                                                                              |
|--------------------------------------------------------------|----------------|---------|-----------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                              | $x_1$          | 9       | mm              |                                                                                                                              |
|                                                              | $x_2$          | 29      | mm              |                                                                                                                              |
|                                                              | $x_3$          | 29      | mm              | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                           | $N_p$          | 102468  | N               | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force                                   | $P_{m,\infty}$ | 212819  | N               | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                          | $N_s$          | -315287 | N               | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
| Required reinforcement area                                  | $A_{sl,req}$   | -631    | mm <sup>2</sup> | $N_s = f_{yk} * A_{sl}$                                                                                                      |
| $A_{sl} < 0$ mm <sup>2</sup> : minimum reinforcement applies |                |         |                 |                                                                                                                              |

|                                                              |                 |           |                   |                                                                                                                                                                                                            |
|--------------------------------------------------------------|-----------------|-----------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Detailing of reinforcement</b>                            |                 |           |                   |                                                                                                                                                                                                            |
| <i>Minimum reinforcement is required</i>                     |                 |           |                   |                                                                                                                                                                                                            |
|                                                              | $\alpha_e$      | 7         |                   | (Walraven & Braam, 2019)                                                                                                                                                                                   |
| Minimum reinforcement ratio                                  | $\rho_{min}$    | 0,6997%   |                   | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$                                                                                                                                                 |
| Smallest width of the cross-section in the tensile area      | $b_w$           | 100       | mm                |                                                                                                                                                                                                            |
| Applied reinforcement ratio                                  | $\rho$          | 0,731%    | $\leq \rho_{min}$ | $\rho_l = \frac{A_{sl}}{b_w d}$                                                                                                                                                                            |
| <b>Control of the crack width (SLS)</b>                      |                 |           |                   |                                                                                                                                                                                                            |
| Maximum crack width                                          | $w_{max}$       | 30        | mm                | EN 1992-1-1/NB                                                                                                                                                                                             |
| Ratio of bond strength of prestressing and reinforcing steel | $\xi$           | 0,70      |                   | EN 1992-1-1                                                                                                                                                                                                |
| Bonding factor of prestressing steel                         | $\xi_1$         | 0,68      |                   | $\xi_1 = \sqrt{\xi * \frac{\varphi_s}{\varphi_p}}$                                                                                                                                                         |
| Bending moment due to permanent and variable load            | $M_{g+q}$       | 4         | kNm               | $M_{g+q} = \frac{1}{8} q_{SLS} l^2$                                                                                                                                                                        |
| Bending moment due to prestressing                           | $M_p$           | 0         | Nmm               | $M_p = P_{m,\infty} * e_p$                                                                                                                                                                                 |
|                                                              |                 | 0         | kNm               |                                                                                                                                                                                                            |
| Total bending moment                                         | $M_{tot}$       | 4         | kNm               | $M_{tot} = M_{g+q} - M_p$                                                                                                                                                                                  |
| Strain in steel                                              | $\varepsilon_s$ | -0,001499 |                   | $\sum M = 0$ $\Leftrightarrow \varepsilon_s (A_s + \xi_1 A_p) E_s * x_3 + P_{m,\infty} * x_2 = M_{tot}$ $\Leftrightarrow \varepsilon_s = \frac{M_{tot} - P_{m,\infty} * x_2}{(A_s + \xi_1 A_p) E_s * x_3}$ |
| <i>The cross-section is not cracked in SLS</i>               |                 |           |                   |                                                                                                                                                                                                            |

#### K.6.5 Kern area

| Kern area of the full cross-section |            |     |    |                            |   |    |  |
|-------------------------------------|------------|-----|----|----------------------------|---|----|--|
| Normal force centre                 |            |     |    |                            |   |    |  |
| From the top                        | $z_{nc}$   | 142 | mm | $z_{NC} = \frac{ES_z}{EA}$ |   |    |  |
| From the right                      | $y_{nc}$   | 292 | mm | $y_{NC} = \frac{ES_y}{EA}$ |   |    |  |
| Cross-sectional quantities          |            |     |    |                            |   |    |  |
| Slab                                | distance z | 46  | mm | distance y                 | 0 | mm |  |
| Rib                                 |            | -57 | mm |                            | 0 | mm |  |
| Moments of inertia                  |            |     |    |                            |   |    |  |



|                                        |             |                 |      |         |                |                |  |
|----------------------------------------|-------------|-----------------|------|---------|----------------|----------------|--|
| lyy                                    | 612574208,9 | mm <sup>4</sup> |      |         |                |                |  |
| lyz                                    | 0           | mm <sup>4</sup> |      |         |                |                |  |
| lzz                                    | 142954864,9 | mm <sup>4</sup> |      |         |                |                |  |
|                                        |             |                 |      |         |                |                |  |
| Position of kern points                |             |                 |      |         |                |                |  |
| line                                   | y1          | 1/y1            | z1   | 1/z1    | e <sub>y</sub> | e <sub>z</sub> |  |
| top                                    | ∞           | 0               | -142 | -0,0070 | 0              | 26             |  |
| bottom                                 | ∞           | 0               | 64   | 0,0156  | 0              | -59            |  |
|                                        |             |                 |      |         |                |                |  |
|                                        |             |                 |      |         |                |                |  |
| Distance from bottom to k <sub>b</sub> |             |                 | 38   | mm      |                |                |  |
| Distance from bottom to k <sub>t</sub> |             |                 | 123  | mm      |                |                |  |

| Kern area of the cross-section at rib opening |                 |                  |                |                                    |                |                |  |
|-----------------------------------------------|-----------------|------------------|----------------|------------------------------------|----------------|----------------|--|
| Normal force centre                           |                 |                  |                |                                    |                |                |  |
| From the top                                  | z <sub>nc</sub> | 38               | mm             | $z_{NC} = \frac{ES_{\bar{z}}}{EA}$ |                |                |  |
| From the right                                | y <sub>nc</sub> | 292              | mm             | $y_{NC} = \frac{ES_{\bar{y}}}{EA}$ |                |                |  |
|                                               |                 |                  |                |                                    |                |                |  |
| Cross-sectional quantities                    |                 |                  |                |                                    |                |                |  |
| Slab                                          | distance z      | 3                | mm             | distance y                         | 0              | mm             |  |
| Rib                                           |                 | -26              | mm             |                                    | 0              | mm             |  |
|                                               |                 |                  |                |                                    |                |                |  |
| Moments of inertia                            |                 |                  |                |                                    |                |                |  |
| I <sub>yy</sub>                               | 600282542,3     | mm <sup>4</sup>  |                |                                    |                |                |  |
| I <sub>yz</sub>                               | 0               | mm <sup>4</sup>  |                |                                    |                |                |  |
| I <sub>zz</sub>                               | 4105623         | mm <sup>4</sup>  |                |                                    |                |                |  |
|                                               |                 |                  |                |                                    |                |                |  |
| Position of kern points                       |                 |                  |                |                                    |                |                |  |
| line                                          | y <sub>1</sub>  | 1/y <sub>1</sub> | z <sub>1</sub> | 1/z <sub>1</sub>                   | e <sub>y</sub> | e <sub>z</sub> |  |
| top                                           | ∞               | 0                | -38            | -0,0265                            | 0              | 4,7            |  |
| bottom                                        | ∞               | 0                | 21             | 0,0480                             | 0              | -8,5           |  |
|                                               |                 |                  |                |                                    |                |                |  |
|                                               |                 |                  |                |                                    |                |                |  |
| Distance from bottom to k <sub>b</sub>        |                 |                  | 16             | mm                                 |                |                |  |
| Distance from bottom to k <sub>t</sub>        |                 |                  | 29             | mm                                 |                |                |  |

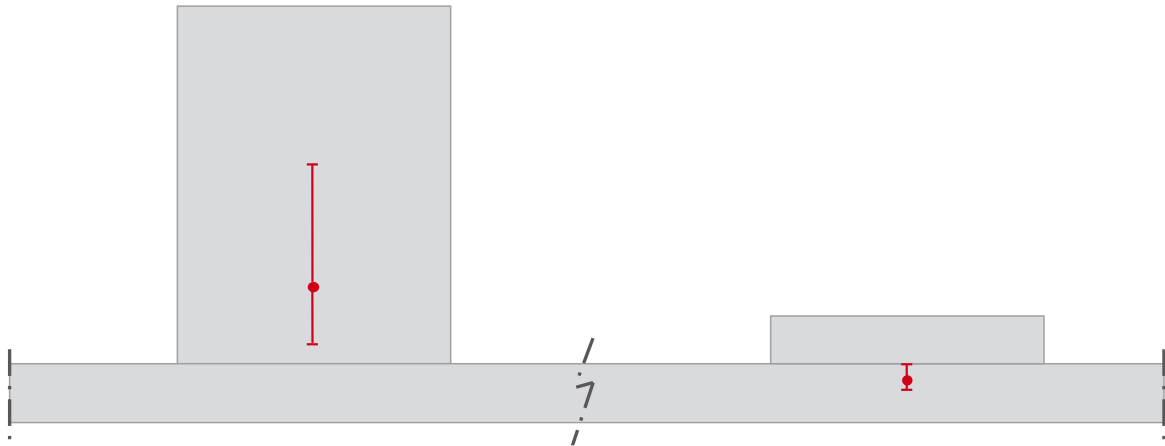


Figure K.79: Comparison of the kern areas for a full cross-section and the cross-section at the rib opening

#### K.6.6 Steel beam



Figure K.80: Schematisation of the load distribution on the steel beam

The spread-out point loads from the ribs on the steel beam are schematised as a distributed load, as shown in Figure K.80. The load on the beam include the own weight of the beam and the weight of the floor elements on both sides of the beam.

| Input                   |                   |          |                   |                          |
|-------------------------|-------------------|----------|-------------------|--------------------------|
| Dimensions              |                   |          |                   |                          |
| Number of ribs          | n                 | 7        |                   |                          |
| Span                    | L                 | 6100     | mm                |                          |
|                         |                   |          |                   |                          |
| Profile properties      |                   |          |                   |                          |
| RHS 200x100 / 8         |                   |          |                   | (Eurocode Applied, n.d.) |
| Height                  | h                 | 200      | mm                |                          |
| Width                   | b                 | 100      | mm                |                          |
| Wall thickness          | t                 | 8        | mm                |                          |
| Outer rounding radius   | r                 | 12       | mm                |                          |
| Area                    | A                 | 4475     | mm <sup>2</sup>   |                          |
| Second moment of area   | I <sub>y</sub>    | 22340000 | mm <sup>4</sup>   |                          |
| Plastic section modulus | W <sub>y,pl</sub> | 282000   | mm <sup>3</sup>   |                          |
| Weight                  | G                 | 35,1     | kg/m              |                          |
|                         |                   | 0,34     | kN/m              |                          |
| Section classification  | Class             | 1        |                   |                          |
|                         |                   |          |                   |                          |
| Steel properties        |                   |          |                   |                          |
| S355                    |                   |          |                   |                          |
| Design yield stress     | f <sub>y</sub>    | 355      | N/mm <sup>2</sup> |                          |
| Young's modulus         | E                 | 210000   | N/mm <sup>2</sup> |                          |
|                         |                   |          |                   |                          |
| Partial factor          | γ <sub>M0</sub>   | 1,0      |                   |                          |

|                                       |           |             |                 |                                                     |
|---------------------------------------|-----------|-------------|-----------------|-----------------------------------------------------|
|                                       |           |             |                 |                                                     |
| <b>Loads</b>                          |           |             |                 |                                                     |
| Load from floor element on beam (ULS) | $V_{ULS}$ | 3,66        | kN              |                                                     |
| Load from floor element on beam (SLS) | $V_{SLS}$ | 3,58        | kN              |                                                     |
|                                       |           |             |                 |                                                     |
| Distributed load (ULS)                | $q_{ULS}$ | 8,75        | kN/m            | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$           |
| Distributed load (SLS)                | $q_{SLS}$ | 8,56        | kN/m            | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$           |
|                                       |           |             |                 |                                                     |
| <b>Load distribution</b>              |           |             |                 |                                                     |
| Bending moment                        | $M_{Ed}$  | 40,7        | kNm             | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$                  |
| Shear force                           | $V_{Ed}$  | 26,7        | kN              | $V_{Ed} = \frac{1}{2} q_{ULS} L$                    |
|                                       |           |             |                 |                                                     |
| <b>Bending resistance</b>             |           |             |                 |                                                     |
| Bending moment resistance             | $M_{Rd}$  | 100110000   | Nmm             | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$         |
|                                       |           | 100         | kNm             |                                                     |
|                                       |           |             |                 |                                                     |
| Unity check                           | 0,41      | ≤           | 1,0             |                                                     |
|                                       |           |             |                 |                                                     |
| <b>Shear resistance</b>               |           |             |                 |                                                     |
| Shear area                            | $A_v$     | 2983,333333 | mm <sup>2</sup> | $A_v = \frac{A * h}{b + h}$                         |
|                                       |           |             |                 |                                                     |
| Shear force resistance                | $V_{Rd}$  | 611462      | N               | $V_{Rd} = \frac{A_v (f_y / \sqrt{3})}{\gamma_{M0}}$ |
|                                       |           | 611         | kN              |                                                     |
|                                       |           |             |                 |                                                     |
| Unity check                           | 0,044     | ≤           | 1,0             |                                                     |
|                                       |           |             |                 |                                                     |
|                                       |           |             |                 |                                                     |
| <b>Deflection (SLS)</b>               |           |             |                 |                                                     |
| Maximum deflection                    | $w_{max}$ | 12,2        | mm              | $w_{max} = \frac{L}{500}$                           |
| Deflection                            | $w$       | 0,00        | mm              | $w = \frac{5}{384} * \frac{qL}{EI}$                 |
|                                       |           |             |                 |                                                     |
|                                       | 0         | mm          | ≤               | 12,2 mm                                             |

|                           |   |      |    |                          |
|---------------------------|---|------|----|--------------------------|
| <b>Input</b>              |   |      |    |                          |
| <b>Dimensions</b>         |   |      |    |                          |
| Number of ribs            | n | 7    |    |                          |
| Span                      | L | 6100 | mm |                          |
|                           |   |      |    |                          |
| <b>Profile properties</b> |   |      |    |                          |
| RHS 180x100 / 8           |   |      |    | (Eurocode Applied, n.d.) |
| Height                    | h | 180  | mm |                          |

|                                       |                   |           |                   |                                                     |
|---------------------------------------|-------------------|-----------|-------------------|-----------------------------------------------------|
| Width                                 | b                 | 100       | mm                |                                                     |
| Wall thickness                        | t                 | 10        | mm                |                                                     |
| Outer rounding radius                 | r                 | 15        | mm                |                                                     |
| Area                                  | A                 | 5093      | mm <sup>2</sup>   |                                                     |
| Second moment of area                 | I <sub>y</sub>    | 20360000  | mm <sup>4</sup>   |                                                     |
| Plastic section modulus               | W <sub>y,pl</sub> | 287900    | mm <sup>3</sup>   |                                                     |
| Weight                                | G                 | 40        | kg/m              |                                                     |
|                                       |                   | 0,39      | kN/m              |                                                     |
| Section classification                | Class             | 1         |                   |                                                     |
| <b>Steel properties</b>               |                   |           |                   |                                                     |
| S355                                  |                   |           |                   |                                                     |
| Design yield stress                   | f <sub>y</sub>    | 355       | N/mm <sup>2</sup> |                                                     |
| Young's modulus                       | E                 | 210000    | N/mm <sup>2</sup> |                                                     |
|                                       |                   |           |                   |                                                     |
| Partial factor                        | γ <sub>M0</sub>   | 1,0       |                   |                                                     |
| <b>Loads</b>                          |                   |           |                   |                                                     |
| Load from floor element on beam (ULS) | V <sub>ULS</sub>  | 3,66      | kN                |                                                     |
| Load from floor element on beam (SLS) | V <sub>SLS</sub>  | 3,58      | kN                |                                                     |
|                                       |                   |           |                   |                                                     |
| Distributed load (ULS)                | q <sub>ULS</sub>  | 8,80      | kN/m              | $q_{ULS} = 2 * \frac{n * V_{ULS}}{L} + G$           |
| Distributed load (SLS)                | q <sub>SLS</sub>  | 8,61      | kN/m              | $q_{SLS} = 2 * \frac{n * V_{SLS}}{L} + G$           |
|                                       |                   |           |                   |                                                     |
| <b>Load distribution</b>              |                   |           |                   |                                                     |
| Bending moment                        | M <sub>Ed</sub>   | 40,9      | kNm               | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$                  |
| Shear force                           | V <sub>Ed</sub>   | 26,8      | kN                | $V_{Ed} = \frac{1}{2} q_{ULS} L$                    |
|                                       |                   |           |                   |                                                     |
| <b>Bending resistance</b>             |                   |           |                   |                                                     |
| Bending moment resistance             | M <sub>Rd</sub>   | 102204500 | Nmm               | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$         |
|                                       |                   | 102       | kNm               |                                                     |
|                                       |                   |           |                   |                                                     |
| Unity check                           | 0,40              | ≤         | 1,0               |                                                     |
|                                       |                   |           |                   |                                                     |
| <b>Shear resistance</b>               |                   |           |                   |                                                     |
| Shear area                            | A <sub>v</sub>    | 3274      | mm <sup>2</sup>   | $A_v = \frac{A * h}{b + h}$                         |
|                                       |                   |           |                   |                                                     |
| Shear force resistance                | V <sub>Rd</sub>   | 671052    | N                 | $V_{Rd} = \frac{A_v (f_y / \sqrt{3})}{\gamma_{M0}}$ |
|                                       |                   | 671       | kN                |                                                     |
|                                       |                   |           |                   |                                                     |
| Unity check                           | 0,040             | ≤         | 1,0               |                                                     |
|                                       |                   |           |                   |                                                     |

|                         |           |      |    |                                       |
|-------------------------|-----------|------|----|---------------------------------------|
|                         |           |      |    |                                       |
| <b>Deflection (SLS)</b> |           |      |    |                                       |
| Maximum deflection      | $w_{max}$ | 12,2 | mm | $w_{max} = \frac{L}{500}$             |
| Deflection              | $w$       | 0,00 | mm | $w = \frac{5}{384} * \frac{qL^4}{EI}$ |
|                         |           |      |    |                                       |
|                         | 0         | mm   | ≤  | 12,2 mm                               |

## Appendix L Fire resistance

### L.1 Option A.ii: Prestressed long span with accessibility from the top

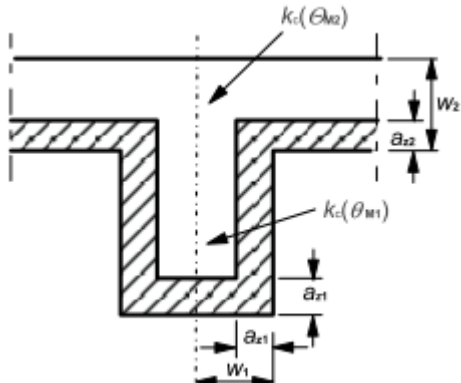
#### L.1.1 Input

|                                           |              |       |                   |                                         |
|-------------------------------------------|--------------|-------|-------------------|-----------------------------------------|
| <b>Dimensions</b>                         |              |       |                   |                                         |
| Span                                      | L            | 6100  | mm                |                                         |
| Width                                     | W            | 3300  | mm                |                                         |
| Number of ribs                            |              | 3     |                   |                                         |
|                                           |              |       |                   |                                         |
| Height slab                               | $h_s$        | 50    | mm                |                                         |
| Height rib                                | $h_r$        | 170   | mm                | ≥170 mm                                 |
| Height rib at opening                     | $h_{r,o}$    | 22,5  | mm                | $h_{r,o} = \frac{h_r - 125}{2}$         |
| Total height                              | $h_t$        | 220   | mm                |                                         |
| Total height at opening                   | $h_{t,o}$    | 72,5  | mm                |                                         |
| Width rib                                 | $b_r$        | 100   | mm                |                                         |
| Space between ribs                        | $b_s$        | 1000  | mm                | ≥170 mm                                 |
| Centre to centre distance between ribs    | $b_{ctc}$    | 1100  | mm                | $b_{ctc} = b_r + b_s$                   |
|                                           |              |       |                   |                                         |
| <b>Concrete properties</b>                |              |       |                   |                                         |
| C30/37                                    |              |       |                   |                                         |
| Density                                   | $\rho_{rep}$ | 25    | kN/m <sup>3</sup> |                                         |
| Characteristic cylinder strength          | $f_{ck}$     | 30    | N/mm <sup>2</sup> |                                         |
| Partial safety factor concrete            | $\gamma_c$   | 1,5   |                   |                                         |
| Design compressive strength               | $f_{cd}$     | 20    | N/mm <sup>2</sup> |                                         |
| Design tensile strength                   | $f_{ctd}$    | 1,35  | N/mm <sup>2</sup> |                                         |
| Mean tensile strength                     | $f_{ctm}$    | 2,9   | N/mm <sup>2</sup> |                                         |
| Young's modulus                           | $E_c$        | 33000 | N/mm <sup>2</sup> |                                         |
|                                           |              |       |                   |                                         |
| <b>Reinforcement properties</b>           |              |       |                   |                                         |
| <b>Longitudinal reinforcement</b>         |              |       |                   |                                         |
| Diameter longitudinal reinforcement       | $\phi_l$     | 6     | mm                |                                         |
| Number of longitudinal reinforcement bars | n            | 5     |                   |                                         |
| Surface area longitudinal reinforcement   | $A_{sl}$     | 141   | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \phi_l^2$ |

|                                                    |                  |        |                   |                                                         |
|----------------------------------------------------|------------------|--------|-------------------|---------------------------------------------------------|
| Spacing of longitudinal reinforcement              | $s_l$            | 220    | mm                | $s_l = \frac{b_{eff}}{n}$                               |
| Effective height of the cross-section              | $d_l$            | 202    | mm                | $d = h - c - \varphi_s - \frac{1}{2}\varphi_l$          |
| <b>Transversal reinforcement top</b>               |                  |        |                   |                                                         |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$  | 4      | mm                |                                                         |
| Number of transversal reinforcement bars top       | $n$              | 12     |                   |                                                         |
| Surface area transversal reinforcement bars top    | $A_{st,t}$       | 151    | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$        |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$        | 83     | mm                | $s_{t,t} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 31     | mm                | $d = h - c - \varphi_s - \frac{1}{2}\varphi_t$          |
| <b>Transversal reinforcement bottom</b>            |                  |        |                   |                                                         |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$  | 4      | mm                |                                                         |
| Number of transversal reinforcement bars bottom    | $n$              | 7      |                   |                                                         |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$       | 88     | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$        |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$        | 143    | mm                | $s_{t,b} = \frac{[1\text{ m}]}{n}$                      |
| Effective height of the cross-section              | $d_l$            | 33     | mm                | $d = h - c - \varphi_s - \frac{1}{2}\varphi_t$          |
| <b>Transversal shear reinforcement</b>             |                  |        |                   |                                                         |
| Diameter transversal shear reinforcement           | $\varphi_s$      | 2      | mm                |                                                         |
| Number of transversal shear reinforcement bars     | $n$              | 1      |                   |                                                         |
| Surface area of transversal shear reinforcement    | $A_{sw}$         | 3      | mm <sup>2</sup>   | $A_{sw} = n * \frac{1}{4} \pi \varphi_s^2$              |
| <b>Concrete cover</b>                              |                  |        |                   |                                                         |
| Minimum cover due to environmental conditions      | $c_{min,dur}$    | 10     | mm                | XC1                                                     |
| Minimum cover due to bond requirement              | $c_{min,b}$      | 6      | mm                | EN 1992-1-1                                             |
| Minimum cover                                      | $c_{min}$        | 10     | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10\text{mm}\}$ |
| Allowance in design for deviation                  | $\Delta c_{dev}$ | 5      | mm                | EN 1992-1-1/NB                                          |
| Nominal cover                                      | $c_{nom}$        | 15     | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$<br>$\geq a_z$      |
| <b>Reinforcement steel</b>                         |                  |        |                   |                                                         |
| <b>B500 B</b>                                      |                  |        |                   |                                                         |
| Yield strength                                     | $f_{yk}$         | 500    | N/mm <sup>2</sup> |                                                         |
| Partial safety factor steel                        | $\gamma_s$       | 1,15   |                   |                                                         |
| Design yield stress                                | $f_{yd}$         | 435    | N/mm <sup>2</sup> |                                                         |
| Young's modulus                                    | $E_s$            | 200000 | N/mm <sup>2</sup> |                                                         |

| Prestressing steel                      |             |      |                   |                                                                                              |
|-----------------------------------------|-------------|------|-------------------|----------------------------------------------------------------------------------------------|
| Y1670C                                  |             |      |                   | EN 10138-2                                                                                   |
| Characteristic tensile strength         | $f_{pk}$    | 1670 | N/mm <sup>2</sup> |                                                                                              |
| 0,1% proof-stress of prestressing steel | $f_{p0,1k}$ | 1503 | N/mm <sup>2</sup> |                                                                                              |
| Diameter of prestressing tendons        | $\varphi_p$ | 8    | mm                |                                                                                              |
| Number of prestressing tendons          | $n$         | 24   |                   |                                                                                              |
| Area of prestressing steel              | $A_p$       | 1206 | mm <sup>2</sup>   | $A_p = n * \frac{1}{4} \pi \varphi_p^2$                                                      |
| Spacing of prestressing tendons         | $s_p$       | 46   | mm                | $s_p = \frac{b_{eff}}{n}$<br>$\leq \max[d_g + 5; 2\varphi_p; 20 \text{ mm}] = 21 \text{ mm}$ |

### L.1.2 Reduced cross-section

| Dimensions                                                                                                                                                                                                                            |              |      |     |                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------|-----|--------------------------|
| Required time resistance                                                                                                                                                                                                              |              | 60   | min |                          |
|  <p>Figure L.1: Reduction of strength and cross-section for a beam exposed to fire from EN 1992-1-2 (Nederlands Normalisatie-instituut, 2011b)</p> |              |      |     |                          |
| Half of the total rib width                                                                                                                                                                                                           | $w_1$        | 50   |     |                          |
| Width of the damaged zone                                                                                                                                                                                                             | $a_{z1}$     | 13   |     | EN 1992-1-2 Appendix B.2 |
| Height of slab                                                                                                                                                                                                                        | $w_2$        | 50   |     |                          |
| Width of the damaged zone                                                                                                                                                                                                             | $a_{z2}$     | 13   |     | EN 1992-1-2 Appendix B.2 |
| Height slab                                                                                                                                                                                                                           | $h_{s,fi}$   | 37   | mm  |                          |
| Height rib                                                                                                                                                                                                                            | $h_{r,fi}$   | 157  | mm  |                          |
| Height rib at opening                                                                                                                                                                                                                 | $h_{r,o,fi}$ | 9,5  | mm  |                          |
| Total height                                                                                                                                                                                                                          | $h_{t,fi}$   | 207  | mm  |                          |
| Total height at opening                                                                                                                                                                                                               | $h_{t,o,fi}$ | 59,5 | mm  |                          |
| Width rib                                                                                                                                                                                                                             | $b_{r,fi}$   | 74   | mm  |                          |
| Space between ribs                                                                                                                                                                                                                    | $b_{s,fi}$   | 1026 | mm  |                          |
| Centre to centre distance between ribs                                                                                                                                                                                                | $b_{ctc}$    | 1100 | mm  |                          |



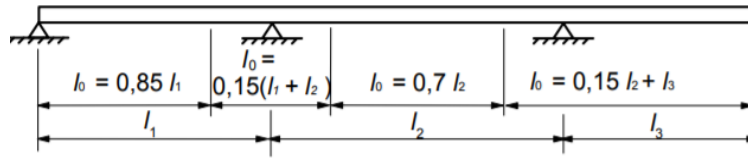


Figure L.2: Definition of  $l_0$ , for calculation of effective flange width (Nederlands Normalisatie-instituut, 2011a)

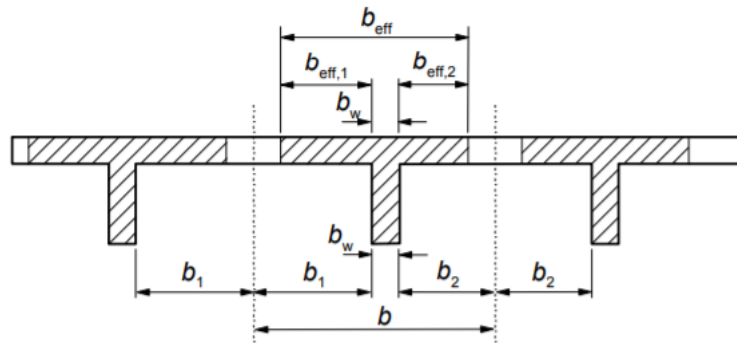


Figure L.3: Effective flange width parameters (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |       |    |                                           |
|------------------------|-------|----|-------------------------------------------|
| $l_1$                  | 6100  | mm | $l_1 = L$                                 |
| $l_0$                  | 5185  | mm | $l_0 = 0,85l_1$                           |
| $b_1$                  | 513   | mm | $b_1 = 0,5 * b_s$                         |
| $b_2$                  | 550   | mm | $b_2 = 0,5 * b_s$                         |
| $b_w$                  | 74    | mm | $b_w = b_r$                               |
| $b$                    | 1100  | mm | $b = b_{ctc}$                             |
| $b_{eff,1}$            | 621,1 | mm | $b_{eff,1} = 0,2b_1 + 0,1l_0 \leq 0,2l_0$ |
| $b_{eff,2}$            | 628,5 | mm | $b_{eff,2} = 0,2b_2 + 0,1l_0 \leq 0,2l_0$ |
| $b_{eff}$              | 1100  | mm | $b_{eff} = \sum b_{eff,i} + b_w \leq b$   |

### Strength reduction

The reduction factors are applied to all strength properties of concrete, reinforcing steel and prestressing steel used in the calculations

|                                                    |          |      |    |                          |
|----------------------------------------------------|----------|------|----|--------------------------|
| Temperature after 60 minutes                       | $\theta$ | 460  | °C | (Braam, 2012)            |
| Reduction factor for concrete compression strength | $k_c$    | 0,64 |    | EN 1992-1-2 Appendix B.2 |
| Reduction factor for concrete tensile strength     | $k_t$    | 0,3  |    | (Braam, 2012)            |
| Reduction factor for reinforcing steel             | $k_s$    | 0,75 |    | EN 1992-1-2              |
| Reduction factor for prestressing steel            | $k_p$    | 0,33 |    | EN 1992-1-2              |

### Kern area of the full cross-section

#### Normal force centre

|              |          |     |    |                            |
|--------------|----------|-----|----|----------------------------|
| From the top | $z_{nc}$ | 154 | mm | $z_{nc} = \frac{ES_z}{EA}$ |
|--------------|----------|-----|----|----------------------------|

|                                   |             |         |       |                                    |       |       |  |
|-----------------------------------|-------------|---------|-------|------------------------------------|-------|-------|--|
| From the right                    | $y_{nc}$    | 550     | mm    | $y_{NC} = \frac{ES_{\bar{y}}}{EA}$ |       |       |  |
| <b>Cross-sectional quantities</b> |             |         |       |                                    |       |       |  |
| Slab                              | distance z  | 35      | mm    | distance y                         | 0     | mm    |  |
| Rib                               |             | -75     | mm    |                                    | 0     | mm    |  |
| Moments of inertia                |             |         |       |                                    |       |       |  |
| $I_{yy}$                          | 4109218347  | $mm^4$  |       |                                    |       |       |  |
| $I_{yz}$                          | 0           | $mm^4$  |       |                                    |       |       |  |
| $I_{zz}$                          | 143218783,6 | $mm^4$  |       |                                    |       |       |  |
| <b>Position of kern points</b>    |             |         |       |                                    |       |       |  |
| line                              | $y_1$       | $1/y_1$ | $z_1$ | $1/z_1$                            | $e_y$ | $e_z$ |  |
| top                               | $\infty$    | 0       | -154  | -0,0065                            | 0     | 18    |  |
| bottom                            | $\infty$    | 0       | 53    | 0,0189                             | 0     | -52   |  |
| Distance from bottom to $k_b$     |             |         | 35    | mm                                 |       |       |  |
| Distance from bottom to $k_t$     |             |         | 105   | mm                                 |       |       |  |

|                                                      |            |         |       |                                    |       |       |  |
|------------------------------------------------------|------------|---------|-------|------------------------------------|-------|-------|--|
| <b>Kern area of the cross-section at rib opening</b> |            |         |       |                                    |       |       |  |
| <b>Normal force centre</b>                           |            |         |       |                                    |       |       |  |
| From the top                                         | $z_{nc}$   | 28      | mm    | $z_{NC} = \frac{ES_{\bar{z}}}{EA}$ |       |       |  |
| From the right                                       | $y_{nc}$   | 550     | mm    | $y_{NC} = \frac{ES_{\bar{y}}}{EA}$ |       |       |  |
| <b>Cross-sectional quantities</b>                    |            |         |       |                                    |       |       |  |
| Slab                                                 | distance z | 13      | mm    | distance y                         | 0     | mm    |  |
| Rib                                                  |            | -23     | mm    |                                    | 0     | mm    |  |
| Moments of inertia                                   |            |         |       |                                    |       |       |  |
| $I_{yy}$                                             | 4104237469 | $mm^4$  |       |                                    |       |       |  |
| $I_{yz}$                                             | 0          | $mm^4$  |       |                                    |       |       |  |
| $I_{zz}$                                             | 12318090   | $mm^4$  |       |                                    |       |       |  |
| <b>Position of kern points</b>                       |            |         |       |                                    |       |       |  |
| line                                                 | $y_1$      | $1/y_1$ | $z_1$ | $1/z_1$                            | $e_y$ | $e_z$ |  |
| top                                                  | $\infty$   | 0       | -28   | -0,0362                            | 0     | 11    |  |
| bottom                                               | $\infty$   | 0       | 32    | 0,0314                             | 0     | -9    |  |
| Distance from bottom to $k_b$                        |            |         | 21    | mm                                 |       |       |  |
| Distance from bottom to $k_t$                        |            |         | 41    | mm                                 |       |       |  |

### L.1.3 Loads

| Permanent loads                                               |                |      |                   |                                                                                                 |
|---------------------------------------------------------------|----------------|------|-------------------|-------------------------------------------------------------------------------------------------|
| Slab                                                          | $g_{slab}$     | 1,25 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                                                   |
| Rib                                                           | $g_{rib}$      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                                    |
| Ceiling panels                                                | $g_{panel}$    | 0,25 | kN/m <sup>2</sup> |                                                                                                 |
| Building services                                             | $g_{services}$ | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                                            |
| Ballast                                                       | $g_{ballast}$  | 1,23 | kN/m <sup>2</sup> | $g_{ballast} = 250 * 0,00981 - g_{slab}$                                                        |
|                                                               |                |      |                   |                                                                                                 |
| Total deadload longitudinal direction                         | $g_{k,l}$      | 3,67 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                     |
| Total deadload transversal direction                          | $g_{k,t}$      | 3,34 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1 m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1 m]$ |
|                                                               |                |      |                   |                                                                                                 |
| Variable load                                                 |                |      |                   |                                                                                                 |
| Variable floor load residential buildings                     | $q_{res}$      | 3,0  | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                                                  |
| Movable partitions                                            | $q_{part}$     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                                     |
| Total variable floor load                                     | $q_{tot}$      | 3,8  | kN/m <sup>2</sup> |                                                                                                 |
|                                                               |                |      |                   |                                                                                                 |
| Total variable floor load in longitudinal direction           | $q_{k,l}$      | 4,18 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                                                   |
| Total variable floor load in transversal direction            | $q_{k,t}$      | 2,6  | kN/m              | $q_{k,t} = q_{tot} * [1 m]$                                                                     |
|                                                               |                |      |                   |                                                                                                 |
| Load combination fire situation                               |                |      |                   |                                                                                                 |
| Factor for frequent value of a variable action                | $\psi_{1,1}$   | 0,5  |                   | EN 1990                                                                                         |
|                                                               |                |      |                   |                                                                                                 |
| Load combination for fire situation in longitudinal direction | $q_{fi,l}$     | 9,29 | kN/m              | $q_{fi} = g_k + \psi_{1,1} q_k$                                                                 |
| Load combination for fire situation in transversal direction  | $q_{fi,t}$     | 7,54 | kN/m              | $q_{fi} = g_k + \psi_{1,1} q_k$                                                                 |

### L.1.4 Preliminary partial prestressing calculations for a reduced cross-section due to fire damage

| Choice of prestressing load                     |
|-------------------------------------------------|
| Chosen to remain uncracked under permanent load |

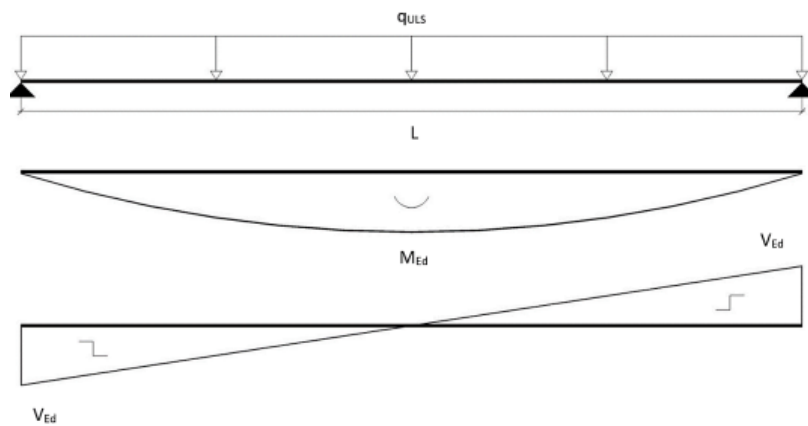


Figure L.4: Load distribution in the longitudinal direction

|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------------------|---------------------------------------------------------|
| Maximum acting bending moment as a result of permanent load only                                                                                  | $M_g$                                                                                                                                                                       | 17              | kNm               | $M_g = \frac{1}{8} q_g l^2$                             |
| <b>Determination of the cross-sectional area of the prestressing steel</b>                                                                        |                                                                                                                                                                             |                 |                   |                                                         |
| To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure                     |                                                                                                                                                                             |                 |                   |                                                         |
| Cross-sectional area of concrete longitudinal direction                                                                                           | $A_c$                                                                                                                                                                       | 52318           | mm <sup>2</sup>   |                                                         |
| Distance of tendon to the centre of gravity                                                                                                       | $e_p$                                                                                                                                                                       | 27              | mm                | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                                                                                                                     | $W_t$                                                                                                                                                                       | 930236          | mm <sup>3</sup>   |                                                         |
|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
|                                                                                                                                                   | $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |                 |                   |                                                         |
| Prestressing force required                                                                                                                       | $P_{m,\infty,req}$                                                                                                                                                          | >               | 384784            | N                                                       |
|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be | 20%                                                                                                                                                                         |                 |                   | (Walraven & Braam, 2019)                                |
|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
| Initial prestressing force required                                                                                                               | $P_{m,0,req}$                                                                                                                                                               | 480980          | N                 | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                    |
|                                                                                                                                                   | $k_7$                                                                                                                                                                       | 0,75            |                   | EN 1992-1-1/NB                                          |
|                                                                                                                                                   | $k_8$                                                                                                                                                                       | 0,85            |                   | EN 1992-1-1/NB                                          |
| Initial prestressing steel stress                                                                                                                 | $\sigma_{pm,0}$                                                                                                                                                             | 413             | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$   |
| Minimum required amount of prestressing steel                                                                                                     | $A_{p,req}$                                                                                                                                                                 | 1164            | mm <sup>2</sup>   | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$             |
|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
| Amount of prestressing steel stress                                                                                                               | 1206                                                                                                                                                                        | mm <sup>2</sup> | ≥                 | 1164 mm <sup>2</sup>                                    |
|                                                                                                                                                   |                                                                                                                                                                             |                 |                   |                                                         |
| Prestressing steel stress                                                                                                                         | $\sigma_{pm,\infty}$                                                                                                                                                        | 330,66          | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$              |

|                            |                |        |   |                                           |
|----------------------------|----------------|--------|---|-------------------------------------------|
| Working prestressing force | $P_{m,\infty}$ | 398899 | N | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$ |
| Initial prestressing force | $P_{m,0}$      | 498624 | N | $P_{m,0} = \sigma_{pm,0} * A_p$           |
|                            |                |        |   |                                           |

#### Determination of the required amount of reinforcing steel

|                                                   |                      |          |                   |                                                  |
|---------------------------------------------------|----------------------|----------|-------------------|--------------------------------------------------|
| Bending moment due to permanent and variable load | $M_{g+q}$            | 43       | kNm               | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$              |
| Bending moment due to prestressing                | $M_p$                | 12740336 | Nmm               | $M_p = \gamma_p * P_{m,\infty} * e_p$            |
|                                                   |                      | 13       | kNm               |                                                  |
| Total bending moment                              | $M_{tot}$            | 30       | kNm               | $M_{tot} = M_{g+q} - M_p$                        |
|                                                   |                      |          |                   |                                                  |
| Time dependent losses are estimated to be         | 10%                  |          |                   | (Walraven & Braam, 2019)                         |
| Friction loss is assumed to be                    | 10%                  |          |                   | (Walraven & Braam, 2019)                         |
| Working prestressing steel stress                 | $\sigma_{pm,\infty}$ | 335      | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$ |
|                                                   |                      |          |                   |                                                  |

It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0,1k}$ )

|  |                |     |                   |                                  |
|--|----------------|-----|-------------------|----------------------------------|
|  | $\Delta\sigma$ | 161 | N/mm <sup>2</sup> | $f_{p0,1k} - \sigma_{pm,\infty}$ |
|  |                |     |                   |                                  |

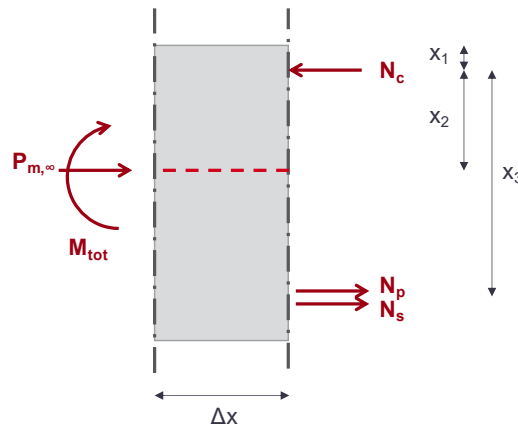


Figure L.5: Total bending moment around the resulting concrete compressive

|                             |                                                           |         |                 |                                                                        |
|-----------------------------|-----------------------------------------------------------|---------|-----------------|------------------------------------------------------------------------|
|                             | $x_1$                                                     | 50      | mm              |                                                                        |
|                             | $x_2$                                                     | 104     | mm              |                                                                        |
|                             | $x_3$                                                     | 131     | mm              | $x_3 = e_p + x_2$                                                      |
| Prestressing force          | $N_p$                                                     | 194463  | N               | $N_p = \Delta\sigma * A_p$                                             |
| Working prestressing force  | $P_{m,\infty}$                                            | 403885  | N               | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                              |
|                             |                                                           |         |                 | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$                     |
| Rebar tensile force         | $N_s$                                                     | -516023 | N               | $\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                             |                                                           |         |                 |                                                                        |
| Required reinforcement area | $A_{sl,req}$                                              | -1375   | mm <sup>2</sup> | $N_s = f_{yk} * A_{sl}$                                                |
|                             | $A_{sl} < 0 \text{ mm}^2$ : minimum reinforcement applies |         |                 |                                                                        |
|                             |                                                           |         |                 |                                                                        |

#### Detailing of reinforcement

Minimum reinforcement is required

|  |            |   |  |                          |
|--|------------|---|--|--------------------------|
|  | $\alpha_e$ | 7 |  | (Walraven & Braam, 2019) |
|--|------------|---|--|--------------------------|

|                                                         |              |         |                   |                                                            |
|---------------------------------------------------------|--------------|---------|-------------------|------------------------------------------------------------|
| Minimum reinforcement ratio                             | $\rho_{min}$ | 0,2719% |                   | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$ |
| Smallest width of the cross-section in the tensile area | $b_w$        | 74      | mm                |                                                            |
| Applied reinforcement ratio                             | $\rho$       | 0,946%  | $\leq \rho_{min}$ | $\rho_l = \frac{A_{sl}}{b_w d}$                            |

### L.1.5 Preliminary partial prestressing calculations for a reduced cross-section due to fire damage at rib openings

#### Choice of prestressing load

Chosen to remain uncracked under permanent load

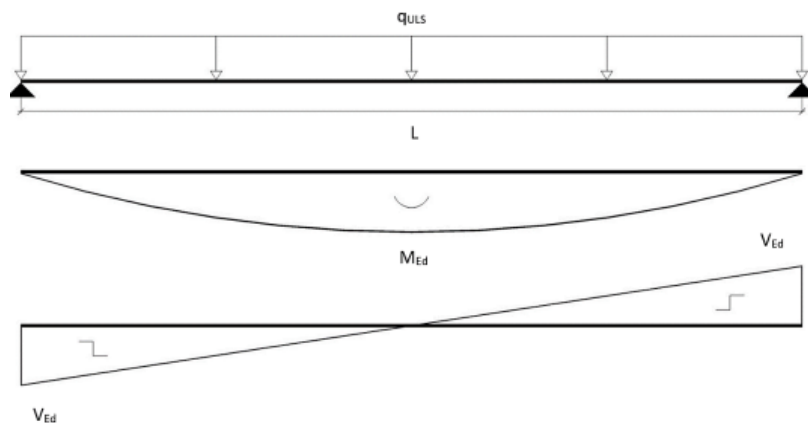


Figure L.6: Load distribution in the longitudinal direction

|                                                                  |       |       |     |                                  |
|------------------------------------------------------------------|-------|-------|-----|----------------------------------|
| Distance from the end of the beam that has a rib opening         | $x$   | 202,5 | mm  |                                  |
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 2,2   | kNm | $M(x) = \frac{q_g x}{2} (l - x)$ |

#### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                                                        |                                                                                                                                                                             |        |                          |                                                         |
|----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|--------------------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction                                | $A_c$                                                                                                                                                                       | 41403  | mm <sup>2</sup>          |                                                         |
| Distance of tendon to the centre of gravity                                            | $e_p$                                                                                                                                                                       | 0      | mm                       | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                                                          | $W_t$                                                                                                                                                                       | 446223 | mm <sup>3</sup>          |                                                         |
|                                                                                        | $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |        |                          |                                                         |
| Prestressing force required                                                            | $P_{m,\infty,req}$                                                                                                                                                          | >      | 203486                   | N                                                       |
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the | 20%                                                                                                                                                                         |        | (Walraven & Braam, 2019) |                                                         |

|                                                                   |                      |                 |                   |                                                       |
|-------------------------------------------------------------------|----------------------|-----------------|-------------------|-------------------------------------------------------|
| <i>prestressing steel and tendon friction are estimated to be</i> |                      |                 |                   |                                                       |
|                                                                   |                      |                 |                   |                                                       |
| Initial prestressing force required                               | $P_{m,0,req}$        | 254357          | N                 | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                  |
|                                                                   | $k_7$                | 0,75            |                   | EN 1992-1-1/NB                                        |
|                                                                   | $k_8$                | 0,85            |                   | EN 1992-1-1/NB                                        |
| Initial prestressing steel stress                                 | $\sigma_{pm,0}$      | 413             | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |
| Minimum required amount of prestressing steel                     | $A_{p,req}$          | 615             | mm <sup>2</sup>   | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$           |
|                                                                   |                      |                 |                   |                                                       |
| Amount of prestressing steel stress                               | 1206                 | mm <sup>2</sup> | ≥                 | 615 mm <sup>2</sup>                                   |
|                                                                   |                      |                 |                   |                                                       |
| Prestressing steel stress                                         | $\sigma_{pm,\infty}$ | 331             | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$            |
| Working prestressing force                                        | $P_{m,\infty}$       | 398899          | N                 | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$             |
| Initial prestressing force                                        | $P_{m,0}$            | 498624          | N                 | $P_{m,0} = \sigma_{pm,0} * A_p$                       |
|                                                                   |                      |                 |                   |                                                       |

#### Determination of the required amount of reinforcing steel

|                                                   |                      |     |                   |                                                  |
|---------------------------------------------------|----------------------|-----|-------------------|--------------------------------------------------|
| Bending moment due to permanent and variable load | $M_{g+q}$            | 6   | kNm               | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$              |
| Bending moment due to prestressing                | $M_p$                | 0   | Nmm               | $M_p = \gamma_P * P_{m,\infty} * e_p$            |
|                                                   |                      | 0   | kNm               |                                                  |
| Total bending moment                              | $M_{tot}$            | 6   | kNm               | $M_{tot} = M_{g+q} - M_p$                        |
|                                                   |                      |     |                   |                                                  |
| Time dependent losses are estimated to be         | 10%                  |     |                   | (Walraven & Braam, 2019)                         |
| Friction loss is assumed to be                    | 10%                  |     |                   | (Walraven & Braam, 2019)                         |
| Working prestressing steel stress                 | $\sigma_{pm,\infty}$ | 335 | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$ |
|                                                   |                      |     |                   |                                                  |

It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0,1k}$ )

|  |                |     |                   |                                  |
|--|----------------|-----|-------------------|----------------------------------|
|  | $\Delta\sigma$ | 161 | N/mm <sup>2</sup> | $f_{p0,1k} - \sigma_{pm,\infty}$ |
|  |                |     |                   |                                  |

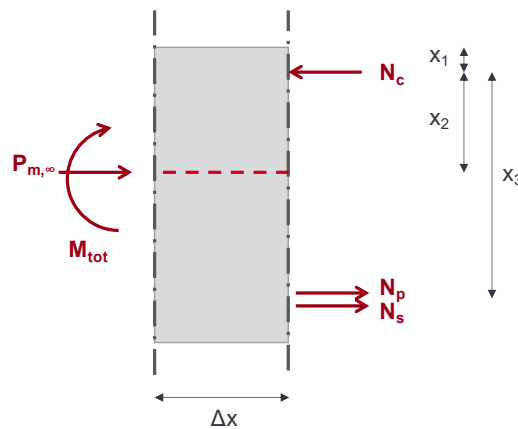


Figure L.7: Total bending moment around the resulting concrete compressive

|  |       |    |    |  |
|--|-------|----|----|--|
|  | $x_1$ | 9  | mm |  |
|  | $x_2$ | 37 | mm |  |



|                                                           |                |         |                 |                                                                                                                              |
|-----------------------------------------------------------|----------------|---------|-----------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                           | $x_3$          | 37      | mm              | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                        | $N_p$          | 194463  | N               | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force                                | $P_{m,\infty}$ | 403885  | N               | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                       | $N_s$          | -598348 | N               | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
| Required reinforcement area                               | $A_{sl,req}$   | -1596   | mm <sup>2</sup> | $N_s = f_{yk} * A_{sl}$                                                                                                      |
| $A_{sl} < 0 \text{ mm}^2$ : minimum reinforcement applies |                |         |                 |                                                                                                                              |

### Detailing of reinforcement

Minimum reinforcement is required

|                                                         |              |         |                   |                                                            |
|---------------------------------------------------------|--------------|---------|-------------------|------------------------------------------------------------|
|                                                         | $\alpha_e$   | 7       |                   | (Walraven & Braam, 2019)                                   |
| Minimum reinforcement ratio                             | $\rho_{min}$ | 0,2719% |                   | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$ |
| Smallest width of the cross-section in the tensile area | $b_w$        | 74      | mm                |                                                            |
| Applied reinforcement ratio                             | $\rho$       | 0,946%  | $\leq \rho_{min}$ | $\rho_l = \frac{A_{sl}}{b_w d}$                            |

### L.1.6 Calculations for a reduced cross-section due to fire damage in the transversal direction

For the transversal directions calculations, the effect of the prestressing in the longitudinal direction is not taken into account.

### Load distribution

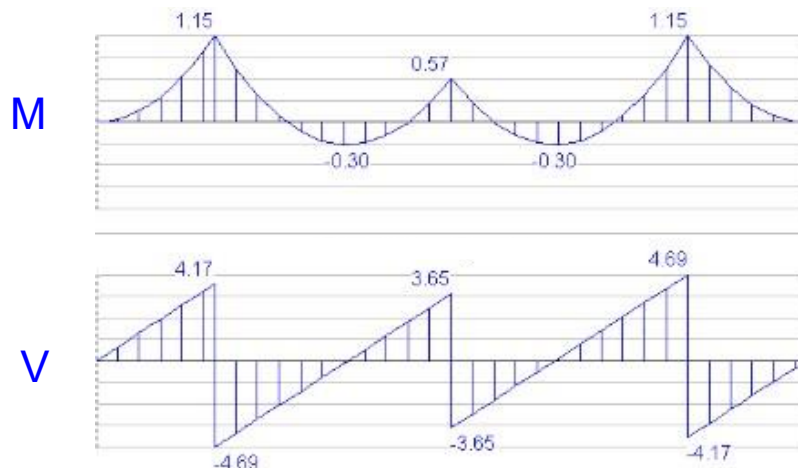


Figure L.8: Load distribution in transversal direction (using Technosoft Liggers)

|                                         |                 |      |     |  |
|-----------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment at top    | $M_{Ed,top}$    | 1,15 | kNm |  |
| Maximum acting bending moment at bottom | $M_{Ed,bottom}$ | 0,3  | kNm |  |
| Maximum acting shear force              | $V_{Ed}$        | 4,69 | kN  |  |

### Bending moment reinforcement

#### Bending moment reinforcement at the top

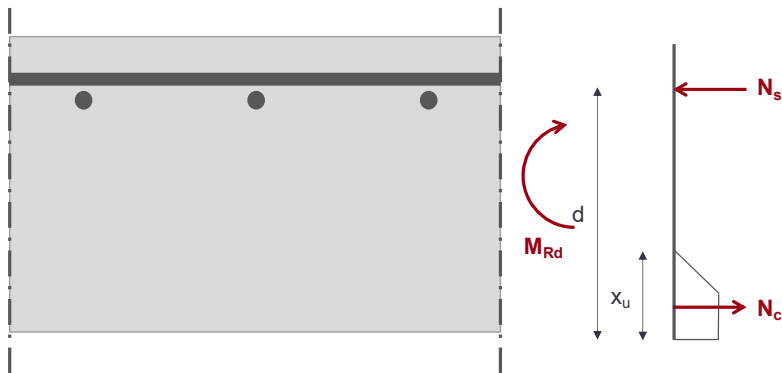


Figure L.9: Concrete cross-section top reinforcement

|                                  |          |         |     |                                                                                   |
|----------------------------------|----------|---------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 49173   | N   | $N_s = A_{st,t} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |         | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 5,12    | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 1426126 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 1,43    | kNm |                                                                                   |
| Unity Check                      | 0,81     | ≤       | 1,0 |                                                                                   |

#### Bending moment reinforcement at the bottom

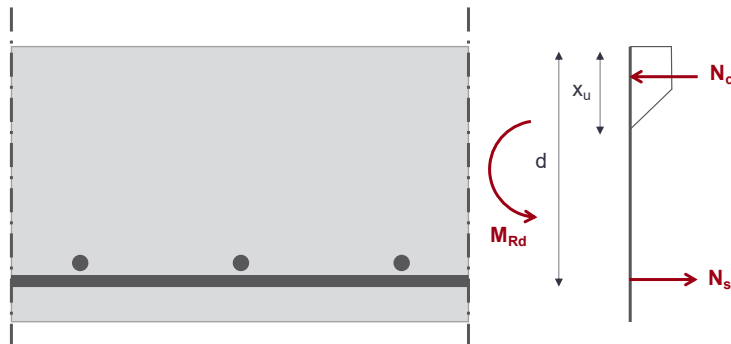


Figure L.10: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 28684  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 2,99   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 913150 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,91   | kNm |                                                                                   |
| Unity Check                      | 0,33     | ≤      | 1,0 |                                                                                   |

## Shear in web-flange interface

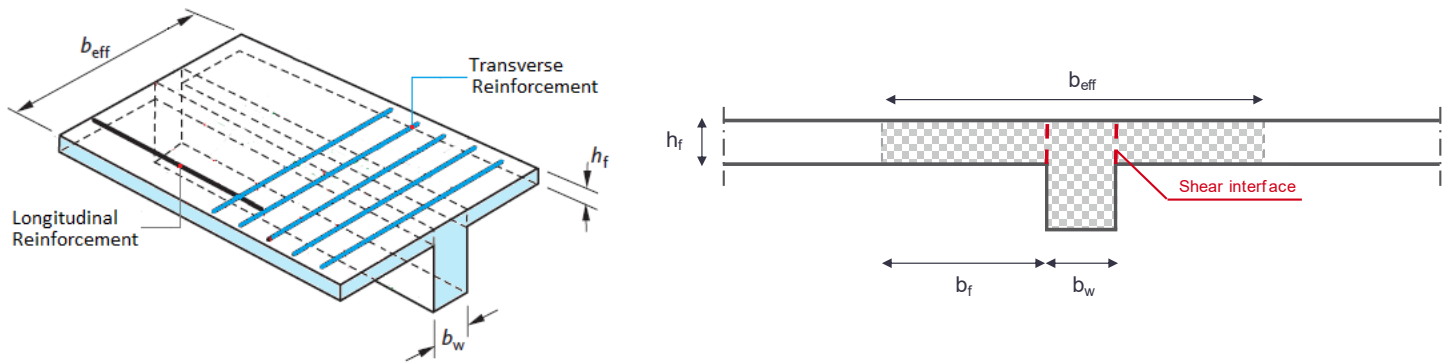


Figure L.11: Parameters for shear in the web-flange interface

|                                            |            |        |                     |                                                                                                                                                                     |
|--------------------------------------------|------------|--------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Width of flange                            | $b_f$      | 513    | mm                  |                                                                                                                                                                     |
| Shear stress                               | $v_{Ed}$   | 0,33   | N/mm <sup>2</sup>   | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$                                                                                                          |
|                                            | $k$        | 0,4    |                     | EN 1992-1-1/NB                                                                                                                                                      |
|                                            | 0,33       | ≤      | 0,162               | $v_{ed} \leq k * f_{ctd}$<br>Transverse reinforcement required                                                                                                      |
| Required transversal shear reinforcement   |            |        |                     |                                                                                                                                                                     |
|                                            | $A_{st}/s$ | 0,0002 | mm <sup>2</sup> /mm | $\frac{A_{st}}{s} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{2 * f_{yd}} * \frac{1}{\cot \theta_f}$<br>$1,0 \leq \theta_f \leq 1,25$ for tension flanges                 |
| Spacing of transversal shear reinforcement | $s$        | 13511  | mm                  | Spacing is larger than the span of the floor slab. A solution could be to locally increase the height of the slab to reduce the shear force in the shear interface. |

## L.2 Option B.ii: Prestressed short span with accessibility from the top

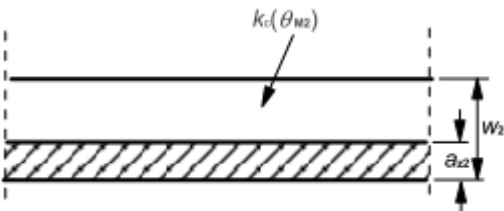
### L.2.1 Input

| Dimensions                             |           |      |    |                                 |
|----------------------------------------|-----------|------|----|---------------------------------|
| Span                                   | L         | 6100 | mm |                                 |
| Width                                  | W         | 3300 | mm |                                 |
| Number of ribs                         |           | 7    |    |                                 |
| Height slab                            | $h_s$     | 50   | mm |                                 |
| Height rib                             | $h_r$     | 170  | mm | ≥170 mm                         |
| Height rib at opening                  | $h_{r,o}$ | 22,5 | mm | $h_{r,o} = \frac{h_r - 125}{2}$ |
| Total height                           | $h_t$     | 220  | mm |                                 |
| Total height at opening                | $h_{t,o}$ | 72,5 | mm |                                 |
| Width rib                              | $b_r$     | 100  | mm |                                 |
| Space between ribs                     | $b_s$     | 1000 | mm | ≥170 mm                         |
| Centre to centre distance between ribs | $b_{ctc}$ | 1100 | mm | $b_{ctc} = b_r + b_s$           |

|                                                    |                 |       |                   |                                                  |
|----------------------------------------------------|-----------------|-------|-------------------|--------------------------------------------------|
|                                                    |                 |       |                   |                                                  |
| <b>Concrete properties</b>                         |                 |       |                   |                                                  |
| C30/37                                             |                 |       |                   |                                                  |
| Density                                            | $\rho_{rep}$    | 25    | kN/m <sup>3</sup> |                                                  |
| Characteristic cylinder strength                   | $f_{ck}$        | 30    | N/mm <sup>2</sup> |                                                  |
| Partial safety factor concrete                     | $\gamma_c$      | 1,5   |                   |                                                  |
| Design compressive strength                        | $f_{cd}$        | 20    | N/mm <sup>2</sup> |                                                  |
| Design tensile strength                            | $f_{ctd}$       | 1,35  | N/mm <sup>2</sup> |                                                  |
| Mean tensile strength                              | $f_{ctm}$       | 2,9   | N/mm <sup>2</sup> |                                                  |
| Young's modulus                                    | $E_c$           | 33000 | N/mm <sup>2</sup> |                                                  |
|                                                    |                 |       |                   |                                                  |
| <b>Reinforcement properties</b>                    |                 |       |                   |                                                  |
| <b>Longitudinal reinforcement</b>                  |                 |       |                   |                                                  |
| Diameter longitudinal reinforcement                | $\varphi_l$     | 4     | mm                |                                                  |
| Number of longitudinal reinforcement bars          | $n$             | 12    |                   |                                                  |
| Surface area longitudinal reinforcement            | $A_{sl}$        | 151   | mm <sup>2</sup>   | $A_{sl} = n * \frac{1}{4} \pi \varphi_l^2$       |
| Spacing of longitudinal reinforcement              | $s_l$           | 49    | mm                | $s_l = \frac{b_{eff}}{n}$                        |
| Effective height of the cross-section              | $d_l$           | 203   | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_l$  |
|                                                    |                 |       |                   |                                                  |
| <b>Transversal reinforcement top</b>               |                 |       |                   |                                                  |
| Diameter transversal reinforcement top             | $\varphi_{t,t}$ | 4     | mm                |                                                  |
| Number of transversal reinforcement bars top       | $n$             | 7     |                   |                                                  |
| Surface area transversal reinforcement bars top    | $A_{st,t}$      | 88    | mm <sup>2</sup>   | $A_{st,t} = n * \frac{1}{4} \pi \varphi_{t,t}^2$ |
| Spacing of transversal reinforcement bars top      | $s_{t,t}$       | 143   | mm                | $s_{t,t} = \frac{[1\ m]}{n}$                     |
| Effective height of the cross-section              | $d_l$           | 31    | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$  |
|                                                    |                 |       |                   |                                                  |
| <b>Transversal reinforcement bottom</b>            |                 |       |                   |                                                  |
| Diameter transversal reinforcement bottom          | $\varphi_{t,b}$ | 4     | mm                |                                                  |
| Number of transversal reinforcement bars bottom    | $n$             | 7     |                   |                                                  |
| Surface area transversal reinforcement bars bottom | $A_{st,b}$      | 88    | mm <sup>2</sup>   | $A_{st,b} = n * \frac{1}{4} \pi \varphi_{t,b}^2$ |
| Spacing of transversal reinforcement bars bottom   | $s_{t,b}$       | 143   | mm                | $s_{t,b} = \frac{[1\ m]}{n}$                     |
| Effective height of the cross-section              | $d_l$           | 33    | mm                | $d = h - c - \varphi_s - \frac{1}{2} \varphi_t$  |
|                                                    |                 |       |                   |                                                  |
| <b>Transversal shear reinforcement</b>             |                 |       |                   |                                                  |
| Diameter transversal shear reinforcement           | $\varphi_s$     | 2     | mm                |                                                  |
| Number of transversal shear reinforcement bars     | $n$             | 1     |                   |                                                  |

|                                                 |                  |        |                   |                                                                                           |
|-------------------------------------------------|------------------|--------|-------------------|-------------------------------------------------------------------------------------------|
| Surface area of transversal shear reinforcement | $A_{sw}$         | 3      | mm <sup>2</sup>   | $A_{sw} = n * \frac{1}{4} \pi \phi_s^2$                                                   |
| <b>Concrete cover</b>                           |                  |        |                   |                                                                                           |
| Minimum cover due to environmental conditions   | $c_{min,dur}$    | 10     | mm                | XC1                                                                                       |
| Minimum cover due to bond requirement           | $c_{min,b}$      | 6      | mm                | EN 1992-1-1                                                                               |
| Minimum cover                                   | $c_{min}$        | 10     | mm                | $c_{min} = \max\{c_{min,b}; c_{min,dur}; 10mm\}$                                          |
| Allowance in design for deviation               | $\Delta c_{dev}$ | 5      | mm                | EN 1992-1-1/NB                                                                            |
| Nominal cover                                   | $c_{nom}$        | 15     | mm                | $c_{nom} = c_{min} + \Delta c_{dev}$<br>$\geq a_z$                                        |
| <b>Reinforcement steel</b>                      |                  |        |                   |                                                                                           |
| <b>B500 B</b>                                   |                  |        |                   |                                                                                           |
| Yield strength                                  | $f_{yk}$         | 500    | N/mm <sup>2</sup> |                                                                                           |
| Partial safety factor steel                     | $\gamma_s$       | 1,15   |                   |                                                                                           |
| Design yield stress                             | $f_{yd}$         | 435    | N/mm <sup>2</sup> |                                                                                           |
| Young's modulus                                 | $E_s$            | 200000 | N/mm <sup>2</sup> |                                                                                           |
| <b>Prestressing steel</b>                       |                  |        |                   |                                                                                           |
| <b>Y1770C</b>                                   |                  |        |                   |                                                                                           |
| Characteristic tensile strength                 | $f_{pk}$         | 1770   | N/mm <sup>2</sup> | EN 10138-2                                                                                |
| 0,1% proof-stress of prestressing steel         | $f_{p0,1k}$      | 1593   | N/mm <sup>2</sup> |                                                                                           |
| Diameter of prestressing tendons                | $\phi_p$         | 6      | mm                |                                                                                           |
| Number of prestressing tendons                  | $n$              | 9      |                   |                                                                                           |
| Area of prestressing steel                      | $A_p$            | 254    | mm <sup>2</sup>   | $A_p = n * \frac{1}{4} \pi \phi_p^2$                                                      |
| Spacing of prestressing tendons                 | $s_p$            | 65     | mm                | $s_p = \frac{b_{eff}}{n}$<br>$\leq \max[d_g + 5; 2\phi_p; 20 \text{ mm}] = 21 \text{ mm}$ |

## L.2.2 Reduced cross-section

| Dimensions                                                                                                                                                                                                                              |          |    |     |                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----|-----|--------------------------|
| Required time resistance                                                                                                                                                                                                                |          | 60 | min |                          |
|  <p>Figure L.12: Reduction of strength and cross-section for a slab exposed to fire from EN 1992-1-2 (Nederlands Normalisatie-instituut, 2011b)</p> |          |    |     |                          |
| Half of the total rib width                                                                                                                                                                                                             | $w_1$    | 50 |     |                          |
| Width of the damaged zone                                                                                                                                                                                                               | $a_{z1}$ | 13 |     | EN 1992-1-2 Appendix B.2 |

|                                        |              |      |    |                          |
|----------------------------------------|--------------|------|----|--------------------------|
| Height of slab                         | $w_2$        | 50   |    |                          |
| Width of the damaged zone              | $a_{z2}$     | 13   |    | EN 1992-1-2 Appendix B.2 |
| Height slab                            | $h_{s,fi}$   | 37   | mm |                          |
| Height rib                             | $h_{r,fi}$   | 157  | mm |                          |
| Height rib at opening                  | $h_{r,o,fi}$ | 9,5  | mm |                          |
| Total height                           | $h_{t,fi}$   | 207  | mm |                          |
| Total height at opening                | $h_{t,o,fi}$ | 59,5 | mm |                          |
| Width rib                              | $b_{r,fi}$   | 74   | mm |                          |
| Space between ribs                     | $b_{s,fi}$   | 797  | mm |                          |
| Centre to centre distance between ribs | $b_{ctc}$    | 871  | mm |                          |

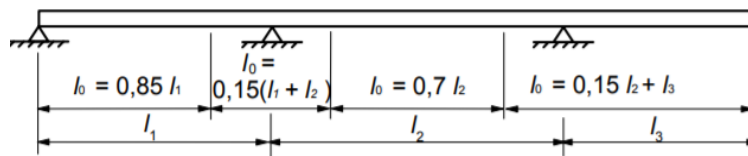


Figure L.13: Definition of  $l_0$ , for calculation of effective flange width (Nederlands Normalisatie-instituut, 2011a)

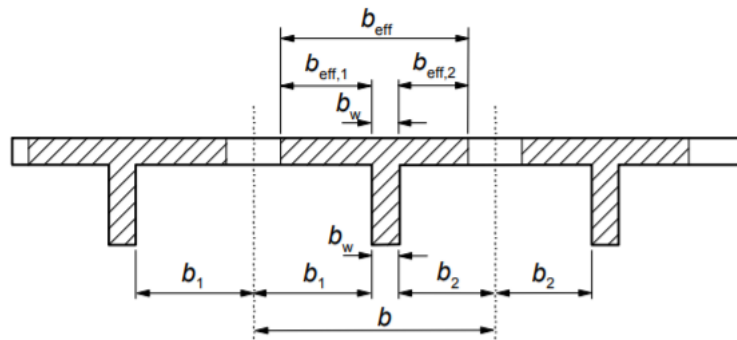


Figure L.14: Effective flange width parameters (Nederlands Normalisatie-instituut, 2011a)

| Effective flange width |      |    |                                           |
|------------------------|------|----|-------------------------------------------|
| $l_1$                  | 6100 | mm | $l_1 = L$                                 |
| $l_0$                  | 5185 | mm | $l_0 = 0,85l_1$                           |
| $b_1$                  | 399  | mm | $b_1 = 0,5 * b_s$                         |
| $b_2$                  | 399  | mm | $b_2 = 0,5 * b_s$                         |
| $b_w$                  | 74   | mm | $b_w = b_r$                               |
| $b$                    | 871  | mm | $b = b_{ctc}$                             |
| $b_{eff,1}$            | 360  | mm | $b_{eff,1} = 0,2b_1 + 0,1l_0 \leq 0,2l_0$ |
| $b_{eff,2}$            | 360  | mm | $b_{eff,2} = 0,2b_2 + 0,1l_0 \leq 0,2l_0$ |
| $b_{eff}$              | 795  | mm | $b_{eff} = \sum b_{eff,i} + b_w \leq b$   |

### Strength reduction

The reduction factors are applied to all strength properties of concrete, reinforcing steel and prestressing steel used in the calculations

|                                                    |          |      |    |                             |
|----------------------------------------------------|----------|------|----|-----------------------------|
| Temperature after 60 minutes                       | $\theta$ | 460  | °C | (Braam, 2012)               |
| Reduction factor for concrete compression strength | $k_c$    | 0,64 |    | EN 1992-1-2<br>Appendix B.2 |
| Reduction factor for concrete tensile strength     | $k_t$    | 0,3  |    | (Braam, 2012)               |
| Reduction factor for reinforcing steel             | $k_s$    | 0,75 |    | EN 1992-1-2                 |
| Reduction factor for prestressing steel            | $k_p$    | 0,33 |    | EN 1992-1-2                 |

### Kern area of the full cross-section

#### Normal force centre

|                |          |     |    |                                    |
|----------------|----------|-----|----|------------------------------------|
| From the top   | $z_{nc}$ | 148 | mm | $z_{nc} = \frac{ES_{\bar{z}}}{EA}$ |
| From the right | $y_{nc}$ | 397 | mm | $y_{nc} = \frac{ES_{\bar{y}}}{EA}$ |
|                |          |     |    |                                    |

#### Cross-sectional quantities

|      |            |     |    |            |   |    |  |
|------|------------|-----|----|------------|---|----|--|
| Slab | distance z | 40  | mm | distance y | 0 | mm |  |
| Rib  |            | -70 | mm |            | 0 | mm |  |
|      |            |     |    |            |   |    |  |

#### Moments of inertia

|          |            |                 |  |
|----------|------------|-----------------|--|
| $I_{yy}$ | 1551548273 | mm <sup>4</sup> |  |
| $I_{yz}$ | 0          | mm <sup>4</sup> |  |
| $I_{zz}$ | 131535012  | mm <sup>4</sup> |  |
|          |            |                 |  |

#### Position of kern points

| line   | $y_1$    | $1/y_1$ | $z_1$ | $1/z_1$ | $e_y$ | $e_z$ |  |
|--------|----------|---------|-------|---------|-------|-------|--|
| top    | $\infty$ | 0       | -148  | -0,0068 | 0     | 22    |  |
| bottom | $\infty$ | 0       | 59    | 0,0170  | 0     | -54   |  |
|        |          |         |       |         |       |       |  |
|        |          |         |       |         |       |       |  |

Distance from bottom to  $k_b$  37 mm

Distance from bottom to  $k_t$  113 mm

### Kern area of the cross-section at rib opening

#### Normal force centre

|                |          |     |    |                                    |
|----------------|----------|-----|----|------------------------------------|
| From the top   | $z_{nc}$ | 27  | mm | $z_{nc} = \frac{ES_{\bar{z}}}{EA}$ |
| From the right | $y_{nc}$ | 397 | mm | $y_{nc} = \frac{ES_{\bar{y}}}{EA}$ |
|                |          |     |    |                                    |

#### Cross-sectional quantities

|      |            |     |    |            |   |    |  |
|------|------------|-----|----|------------|---|----|--|
| Slab | distance z | 14  | mm | distance y | 0 | mm |  |
| Rib  |            | -23 | mm |            | 0 | mm |  |
|      |            |     |    |            |   |    |  |



|                                        |            |                 |     |         |                |                |  |
|----------------------------------------|------------|-----------------|-----|---------|----------------|----------------|--|
| Moments of inertia                     |            |                 |     |         |                |                |  |
| lyy                                    | 1546567395 | mm <sup>4</sup> |     |         |                |                |  |
| lyz                                    | 0          | mm <sup>4</sup> |     |         |                |                |  |
| lzz                                    | 9112974    | mm <sup>4</sup> |     |         |                |                |  |
|                                        |            |                 |     |         |                |                |  |
| Position of kern points                |            |                 |     |         |                |                |  |
| line                                   | y1         | 1/y1            | z1  | 1/z1    | e <sub>y</sub> | e <sub>z</sub> |  |
| top                                    | ∞          | 0               | -27 | -0,0364 | 0              | 11             |  |
| bottom                                 | ∞          | 0               | 32  | 0,0312  | 0              | -9             |  |
|                                        |            |                 |     |         |                |                |  |
|                                        |            |                 |     |         |                |                |  |
| Distance from bottom to k <sub>b</sub> |            |                 | 21  | mm      |                |                |  |
| Distance from bottom to k <sub>t</sub> |            |                 | 41  | mm      |                |                |  |

### L.2.3 Loads

| Permanent loads                                               |                       |      |                   |                                                                                                   |
|---------------------------------------------------------------|-----------------------|------|-------------------|---------------------------------------------------------------------------------------------------|
| Slab                                                          | g <sub>slab</sub>     | 1,25 | kN/m <sup>2</sup> | $g_{slab} = \rho_{rep} * h_s$                                                                     |
| Rib                                                           | g <sub>rib</sub>      | 4,25 | kN/m <sup>2</sup> | $g_{rib} = \rho_{rep} * h_r$                                                                      |
| Ceiling panels                                                | g <sub>panel</sub>    | 0,25 | kN/m <sup>2</sup> |                                                                                                   |
| Building services                                             | g <sub>services</sub> | 0,25 | kN/m <sup>2</sup> | (Van Glabbeek, 2019)                                                                              |
| Ballast                                                       | g <sub>ballast</sub>  | 1,20 | kN/m <sup>2</sup> | $g_{ballast} = 250 * 0,00981 - g_{slab}$                                                          |
|                                                               |                       |      |                   |                                                                                                   |
| Total deadload longitudinal direction                         | g <sub>k,l</sub>      | 3,00 | kN/m              | $g_{k,l} = g_{rib} * b_r + (g_{slab} + g_{panel} + g_{services}) * b_{ctc}$                       |
| Total deadload transversal direction                          | g <sub>k,t</sub>      | 3,44 | kN/m              | $g_{k,t} = \frac{n * g_{rib} * b_r * [1\ m]}{w} + (g_{slab} + g_{panel} + g_{services}) * [1\ m]$ |
|                                                               |                       |      |                   |                                                                                                   |
| Variable load                                                 |                       |      |                   |                                                                                                   |
| Variable floor load residential buildings                     | q <sub>res</sub>      | 3,0  | kN/m <sup>2</sup> | EN 1991-1-1/NB                                                                                    |
| Movable partitions                                            | q <sub>part</sub>     | 0,8  | kN/m <sup>2</sup> | EN 1991-1-1                                                                                       |
| Total variable floor load                                     | q <sub>tot</sub>      | 3,8  | kN/m <sup>2</sup> |                                                                                                   |
|                                                               |                       |      |                   |                                                                                                   |
| Total variable floor load in longitudinal direction           | q <sub>k,l</sub>      | 3,31 | kN/m              | $q_{k,l} = q_{tot} * b_{ctc}$                                                                     |
| Total variable floor load in transversal direction            | q <sub>k,t</sub>      | 3,8  | kN/m              | $q_{k,t} = q_{tot} * [1\ m]$                                                                      |
|                                                               |                       |      |                   |                                                                                                   |
| Load combination fire situation                               |                       |      |                   |                                                                                                   |
| Factor for frequent value of a variable action                | ψ <sub>1,1</sub>      | 0,5  |                   | EN 1990                                                                                           |
|                                                               |                       |      |                   |                                                                                                   |
| Load combination for fire situation in longitudinal direction | q <sub>fi,l</sub>     | 8,17 | kN/m              | $q_{fi} = g_k + \psi_{1,1} q_k$                                                                   |
| Load combination for fire situation in transversal direction  | q <sub>fi,t</sub>     | 5,34 | kN/m              | $q_{fi} = g_k + \psi_{1,1} q_k$                                                                   |

## L.2.4 Preliminary partial prestressing calculations for a reduced cross-section due to fire damage

### Choice of prestressing load

Chosen to remain uncracked under permanent load

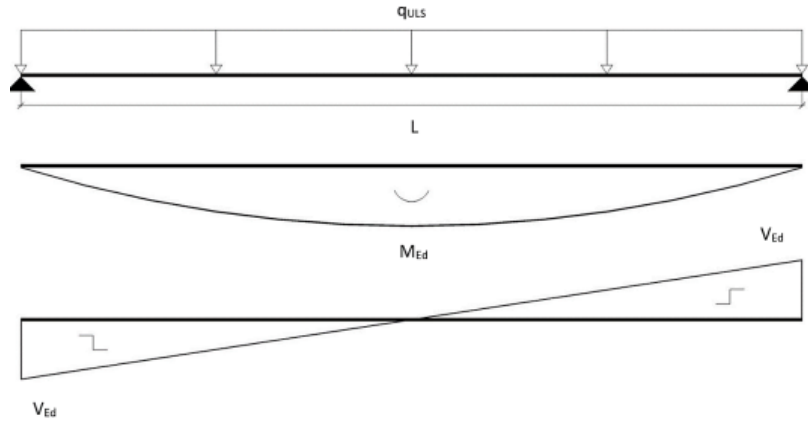


Figure L.15: Load distribution in the longitudinal direction

|                                                                  |       |   |     |                             |
|------------------------------------------------------------------|-------|---|-----|-----------------------------|
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 4 | kNm | $M_g = \frac{1}{8} q_g l^2$ |
|------------------------------------------------------------------|-------|---|-----|-----------------------------|

### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                         |       |        |                 |                                                         |
|---------------------------------------------------------|-------|--------|-----------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction | $A_c$ | 41014  | mm <sup>2</sup> |                                                         |
| Distance of tendon to the centre of gravity             | $e_p$ | 31     | mm              | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                           | $W_t$ | 888613 | mm <sup>3</sup> |                                                         |

$$\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$$

$$\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$$

|                             |                    |   |       |   |
|-----------------------------|--------------------|---|-------|---|
| Prestressing force required | $P_{m,\infty,req}$ | > | 76924 | N |
|-----------------------------|--------------------|---|-------|---|

|                                                                                                                                                   |     |  |  |                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----|--|--|--------------------------|
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be | 20% |  |  | (Walraven & Braam, 2019) |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----|--|--|--------------------------|

|                                               |                 |       |                   |                                                       |
|-----------------------------------------------|-----------------|-------|-------------------|-------------------------------------------------------|
| Initial prestressing force required           | $P_{m,0,req}$   | 96155 | N                 | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                  |
|                                               | $k_7$           | 0,75  |                   | EN 1992-1-1/NB                                        |
|                                               | $k_8$           | 0,85  |                   | EN 1992-1-1/NB                                        |
| Initial prestressing steel stress             | $\sigma_{pm,0}$ | 438   | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |
| Minimum required amount of prestressing steel | $A_{p,req}$     | 219   | mm <sup>2</sup>   | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$           |

|                                     |                      |                 |                   |                                            |                 |
|-------------------------------------|----------------------|-----------------|-------------------|--------------------------------------------|-----------------|
| Amount of prestressing steel stress | 254                  | mm <sup>2</sup> | ≥                 | 219                                        | mm <sup>2</sup> |
| Prestressing steel stress           | $\sigma_{pm,\infty}$ | 350             | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$ |                 |
| Working prestressing force          | $P_{m,\infty}$       | 89181           | N                 | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$  |                 |
| Initial prestressing force          | $P_{m,0}$            | 111477          | N                 | $P_{m,0} = \sigma_{pm,0} * A_p$            |                 |

#### Determination of the required amount of reinforcing steel

|                                                   |                      |         |                                     |                                                  |
|---------------------------------------------------|----------------------|---------|-------------------------------------|--------------------------------------------------|
| Bending moment due to permanent and variable load | $M_{g+q}$            | 11      | kNm                                 | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$              |
| Bending moment due to prestressing                | $M_p$                | 3358732 | Nmm                                 | $M_p = \gamma_P * P_{m,\infty} * e_p$            |
|                                                   |                      | 3       | kNm                                 |                                                  |
| Total bending moment                              | $M_{tot}$            | 8       | kNm                                 | $M_{tot} = M_{g+q} - M_p$                        |
|                                                   |                      |         |                                     |                                                  |
| <i>Time dependent losses are estimated to be</i>  | 10%                  |         | <i>(Walraven &amp; Braam, 2019)</i> |                                                  |
| <i>Friction loss is assumed to be</i>             | 10%                  |         | <i>(Walraven &amp; Braam, 2019)</i> |                                                  |
| Working prestressing steel stress                 | $\sigma_{pm,\infty}$ | 355     | N/mm <sup>2</sup>                   | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$ |
|                                                   |                      |         |                                     |                                                  |

It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0.1k}$ )

|  |                |     |                   |                                  |  |
|--|----------------|-----|-------------------|----------------------------------|--|
|  | $\Delta\sigma$ | 171 | N/mm <sup>2</sup> | $f_{p0.1k} - \sigma_{pm,\infty}$ |  |
|--|----------------|-----|-------------------|----------------------------------|--|

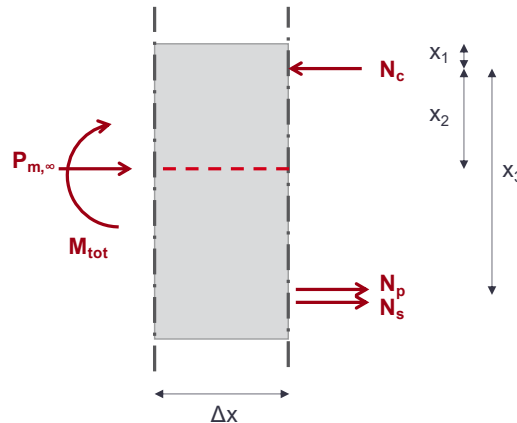


Figure L.16: Total bending moment around the resulting concrete compressive

|                                                                     |                     |         |                 |                                                                                                                              |
|---------------------------------------------------------------------|---------------------|---------|-----------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                                     | x <sub>1</sub>      | 50      | mm              |                                                                                                                              |
|                                                                     | x <sub>2</sub>      | 105     | mm              |                                                                                                                              |
|                                                                     | x <sub>3</sub>      | 136     | mm              | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                                  | N <sub>p</sub>      | 43476   | N               | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force                                          | P <sub>m,∞</sub>    | 90296   | N               | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                                 | N <sub>s</sub>      | -112922 | N               | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                                                                     |                     |         |                 |                                                                                                                              |
| Required reinforcement area                                         | A <sub>sl,req</sub> | -301    | mm <sup>2</sup> | $N_s = f_{yk} * A_{sl}$                                                                                                      |
| A <sub>sl</sub> < 0 mm <sup>2</sup> : minimum reinforcement applies |                     |         |                 |                                                                                                                              |
|                                                                     |                     |         |                 |                                                                                                                              |

## Detailing of reinforcement

Minimum reinforcement is required

|                                                         |              |         |                   |                                                            |
|---------------------------------------------------------|--------------|---------|-------------------|------------------------------------------------------------|
|                                                         | $\alpha_e$   | 7       |                   | (Walraven & Braam, 2019)                                   |
| Minimum reinforcement ratio                             | $\rho_{min}$ | 0,2719% |                   | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$ |
| Smallest width of the cross-section in the tensile area | $b_w$        | 74 mm   |                   |                                                            |
| Applied reinforcement ratio                             | $\rho$       | 1,004%  | $\leq \rho_{min}$ | $\rho_l = \frac{A_{sl}}{b_w d}$                            |

### L.2.5 Preliminary partial prestressing calculations for a reduced cross-section due to fire damage at rib openings

#### Choice of prestressing load

Chosen to remain uncracked under permanent load

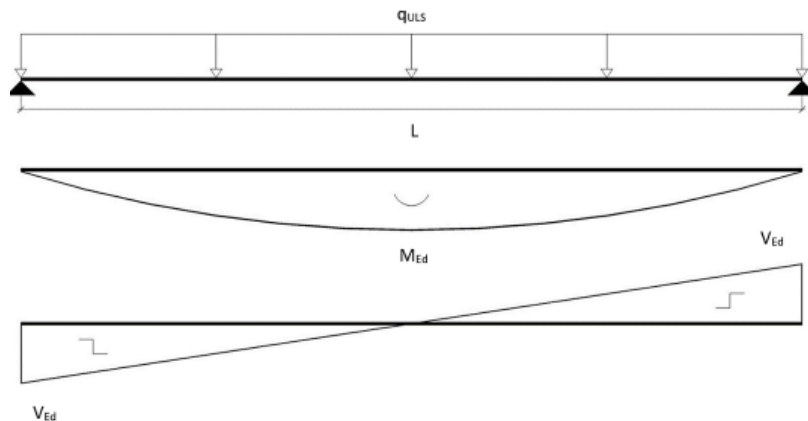


Figure L.17: Load distribution in the longitudinal direction

|                                                                  |       |          |                                  |
|------------------------------------------------------------------|-------|----------|----------------------------------|
| Distance from the end of the beam that has a rib opening         | $x$   | 202,5 mm |                                  |
| Maximum acting bending moment as a result of permanent load only | $M_g$ | 0,9 kNm  | $M(x) = \frac{q_g x}{2} (l - x)$ |

#### Determination of the cross-sectional area of the prestressing steel

To estimate the required amount of prestressing steel, the prestressing is first applied as equivalent loads to the structure

|                                                         |                                                                                                                                                                             |                        |                                                         |
|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|---------------------------------------------------------|
| Cross-sectional area of concrete longitudinal direction | $A_c$                                                                                                                                                                       | 30099 mm <sup>2</sup>  |                                                         |
| Distance of tendon to the centre of gravity             | $e_p$                                                                                                                                                                       | 0 mm                   | Tendon placed in NC of the cross-section at rib opening |
| Section modulus for top fibre                           | $W_t$                                                                                                                                                                       | 331900 mm <sup>3</sup> |                                                         |
|                                                         | $\frac{-P_{m,\infty}}{A_c} - \frac{P_{m,\infty} * e_p}{W_t} + \frac{M_g}{W_t} < 0$ $\Leftrightarrow P_{m,\infty} > \frac{\frac{M_g}{W_t}}{\frac{1}{A_c} + \frac{e_p}{W_t}}$ |                        |                                                         |
| Prestressing force required                             | $P_{m,\infty,req}$                                                                                                                                                          | >                      | 85264 N                                                 |

|                                                                                                                                                   |                      |                 |                   |                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-----------------|-------------------|-------------------------------------------------------|
|                                                                                                                                                   |                      |                 |                   |                                                       |
| The prestressing loss caused by shrinkage and creep of the concrete, relaxation of the prestressing steel and tendon friction are estimated to be | 20%                  |                 |                   | (Walraven & Braam, 2019)                              |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| Initial prestressing force required                                                                                                               | $P_{m,0,req}$        | 106580          | N                 | $P_{m,0} = \frac{P_{m,\infty}}{0.8}$                  |
|                                                                                                                                                   | $k_7$                | 0,75            |                   | EN 1992-1-1/NB                                        |
|                                                                                                                                                   | $k_8$                | 0,85            |                   | EN 1992-1-1/NB                                        |
| Initial prestressing steel stress                                                                                                                 | $\sigma_{pm,0}$      | 438             | N/mm <sup>2</sup> | $\sigma_{pm,0} = \min[k_7 * f_{pk}; k_8 * f_{p0,1k}]$ |
| Minimum required amount of prestressing steel                                                                                                     | $A_{p,req}$          | 243             | mm <sup>2</sup>   | $A_{p,req} = \frac{P_{m,0}}{\sigma_{pm,0}}$           |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| Amount of prestressing steel stress                                                                                                               | 254                  | mm <sup>2</sup> | ≥                 | 243 mm <sup>2</sup>                                   |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| Prestressing steel stress                                                                                                                         | $\sigma_{pm,\infty}$ | 350             | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.8 * \sigma_{pm,0}$            |
| Working prestressing force                                                                                                                        | $P_{m,\infty}$       | 89181           | N                 | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$             |
| Initial prestressing force                                                                                                                        | $P_{m,0}$            | 111477          | N                 | $P_{m,0} = \sigma_{pm,0} * A_p$                       |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| <b>Determination of the required amount of reinforcing steel</b>                                                                                  |                      |                 |                   |                                                       |
| Bending moment due to permanent and variable load                                                                                                 | $M_{g+q}$            | 3               | kNm               | $M_{g+q} = \frac{1}{8} q_{ULS} l^2$                   |
| Bending moment due to prestressing                                                                                                                | $M_p$                | 0               | Nmm               | $M_p = \gamma_P * P_{m,\infty} * e_p$                 |
|                                                                                                                                                   |                      | 0               | kNm               |                                                       |
| Total bending moment                                                                                                                              | $M_{tot}$            | 3               | kNm               | $M_{tot} = M_{g+q} - M_p$                             |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| Time dependent losses are estimated to be                                                                                                         | 10%                  |                 |                   | (Walraven & Braam, 2019)                              |
| Friction loss is assumed to be                                                                                                                    | 10%                  |                 |                   | (Walraven & Braam, 2019)                              |
| Working prestressing steel stress                                                                                                                 | $\sigma_{pm,\infty}$ | 355             | N/mm <sup>2</sup> | $\sigma_{pm,\infty} = 0.9 * 0.9 * \sigma_{pm,0}$      |
|                                                                                                                                                   |                      |                 |                   |                                                       |
| It is assumed that the stress can increase from the working stress to the stress at 0.1% strain limit ( $f_{p0,1k}$ )                             |                      |                 |                   |                                                       |
|                                                                                                                                                   | $\Delta\sigma$       | 171             | N/mm <sup>2</sup> | $f_{p0,1k} - \sigma_{pm,\infty}$                      |
|                                                                                                                                                   |                      |                 |                   |                                                       |

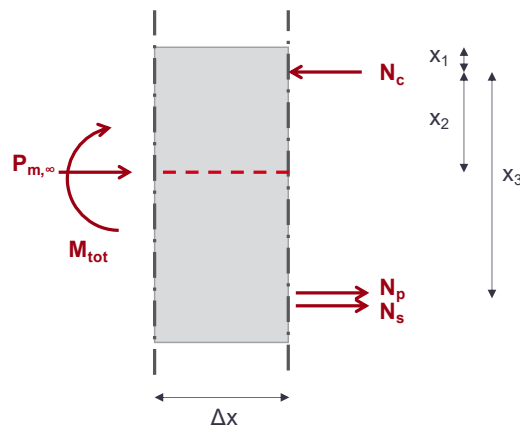


Figure L.18: Total bending moment around the resulting concrete compressive

|                                                         |                                                                     |         |                    |                                                                                                                              |
|---------------------------------------------------------|---------------------------------------------------------------------|---------|--------------------|------------------------------------------------------------------------------------------------------------------------------|
|                                                         | x <sub>1</sub>                                                      | 9       | mm                 |                                                                                                                              |
|                                                         | x <sub>2</sub>                                                      | 36      | mm                 |                                                                                                                              |
|                                                         | x <sub>3</sub>                                                      | 36      | mm                 | $x_3 = e_p + x_2$                                                                                                            |
| Prestressing force                                      | N <sub>p</sub>                                                      | 43476   | N                  | $N_p = \Delta\sigma * A_p$                                                                                                   |
| Working prestressing force                              | P <sub>m,∞</sub>                                                    | 90296   | N                  | $P_{m,\infty} = \sigma_{pm,\infty} * A_p$                                                                                    |
| Rebar tensile force                                     | N <sub>s</sub>                                                      | -133772 | N                  | $M_{tot} = x_2 * P_{m,\infty} + x_3 * (N_s + N_p)$<br>$\Leftrightarrow N_s = \frac{M_{tot} - x_2 * P_{m,\infty}}{x_3} - N_p$ |
|                                                         |                                                                     |         |                    |                                                                                                                              |
| Required reinforcement area                             | A <sub>sl,req</sub>                                                 | -357    | mm <sup>2</sup>    | $N_s = f_{yk} * A_{sl}$                                                                                                      |
|                                                         | A <sub>sl</sub> < 0 mm <sup>2</sup> : minimum reinforcement applies |         |                    |                                                                                                                              |
|                                                         |                                                                     |         |                    |                                                                                                                              |
| Detailing of reinforcement                              |                                                                     |         |                    |                                                                                                                              |
| Minimum reinforcement is required                       |                                                                     |         |                    |                                                                                                                              |
|                                                         | α <sub>e</sub>                                                      | 7       |                    | (Walraven & Braam, 2019)                                                                                                     |
| Minimum reinforcement ratio                             | ρ <sub>min</sub>                                                    | 0,2719% |                    | $\rho_{min} = \frac{1}{\frac{f_{yd}}{f_{ctm}} - \alpha_e}$                                                                   |
|                                                         |                                                                     |         |                    |                                                                                                                              |
| Smallest width of the cross-section in the tensile area | b <sub>w</sub>                                                      | 74      | mm                 |                                                                                                                              |
| Applied reinforcement ratio                             | ρ                                                                   | 1,004%  | ≤ ρ <sub>min</sub> | $\rho_l = \frac{A_{sl}}{b_w d}$                                                                                              |

### L.2.6 Calculations for a reduced cross-section due to fire damage in the transversal direction

For the transversal directions calculations, the effect of the prestressing in the longitudinal direction is not taken into account.

#### Load distribution

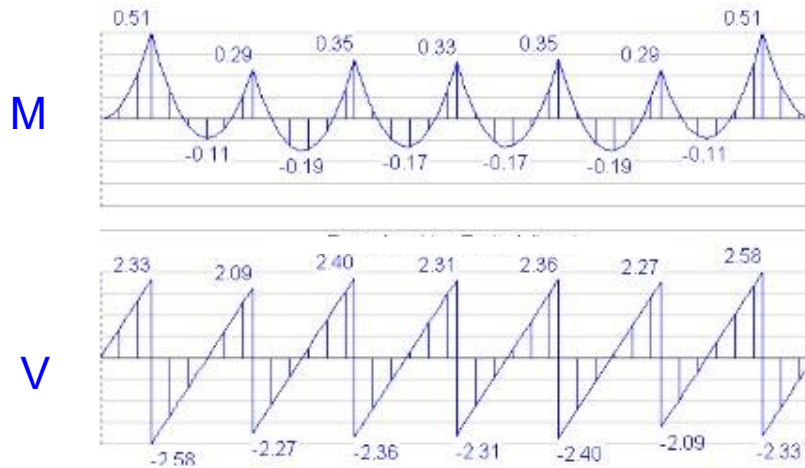


Figure L.19: Load distribution in transversal direction (using Technosoft Liggers)

|                                         |                 |      |     |  |
|-----------------------------------------|-----------------|------|-----|--|
| Maximum acting bending moment at top    | $M_{Ed,top}$    | 0,51 | kNm |  |
| Maximum acting bending moment at bottom | $M_{Ed,bottom}$ | 0,19 | kNm |  |
| Maximum acting shear force              | $V_{Ed}$        | 2,58 | kN  |  |
|                                         |                 |      |     |  |

#### Bending moment reinforcement

##### Bending moment reinforcement at the top

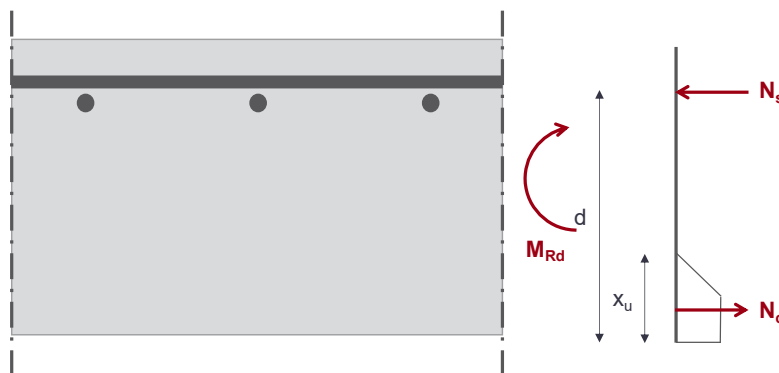


Figure L.20: Concrete cross-section top reinforcement

|                                  |          |        |     |                                                                             |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 28684  | N   | $N_s = A_{st,t} * f_{yd}$                                                   |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\ m]$                                 |
| Concrete compressive zone height | $x_u$    | 2,99   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\ m]}$ |
|                                  |          |        |     |                                                                             |
| Bending moment resistance        | $M_{Rd}$ | 855782 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                              |
|                                  |          | 0,86   | kNm |                                                                             |



|             |      |   |     |  |
|-------------|------|---|-----|--|
| Unity Check | 0,60 | ≤ | 1,0 |  |
|-------------|------|---|-----|--|

#### Bending moment reinforcement at the bottom

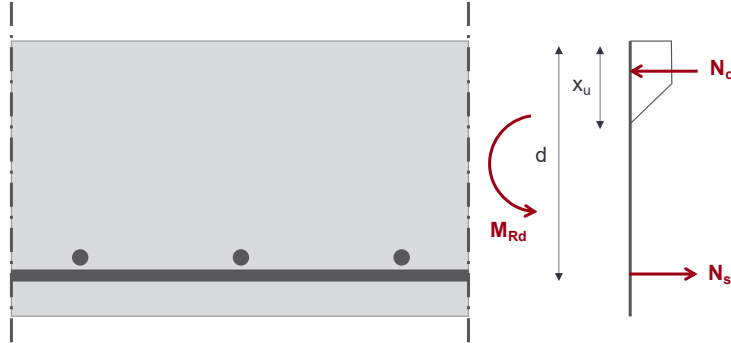


Figure L.21: Concrete cross-section bottom reinforcement

|                                  |          |        |     |                                                                                   |
|----------------------------------|----------|--------|-----|-----------------------------------------------------------------------------------|
| Rebar tensile force              | $N_s$    | 28684  | N   | $N_s = A_{st,b} * f_{yd}$                                                         |
| Concrete compressive force       | $N_c$    |        | N   | $N_c = \frac{3}{4} * x_u * f_{cd} * [1\text{ m}]$                                 |
| Concrete compressive zone height | $x_u$    | 2,99   | mm  | $N_c = N_s \Leftrightarrow x_u = \frac{N_s}{\frac{3}{4} * f_{cd} * [1\text{ m}]}$ |
| Bending moment resistance        | $M_{Rd}$ | 913150 | Nmm | $M_{Rd} = N_s * (d - 0.39x_u)$                                                    |
|                                  |          | 0,91   | kNm |                                                                                   |
| Unity Check                      | 0,21     | ≤      | 1,0 |                                                                                   |

#### Shear in web-flange interface

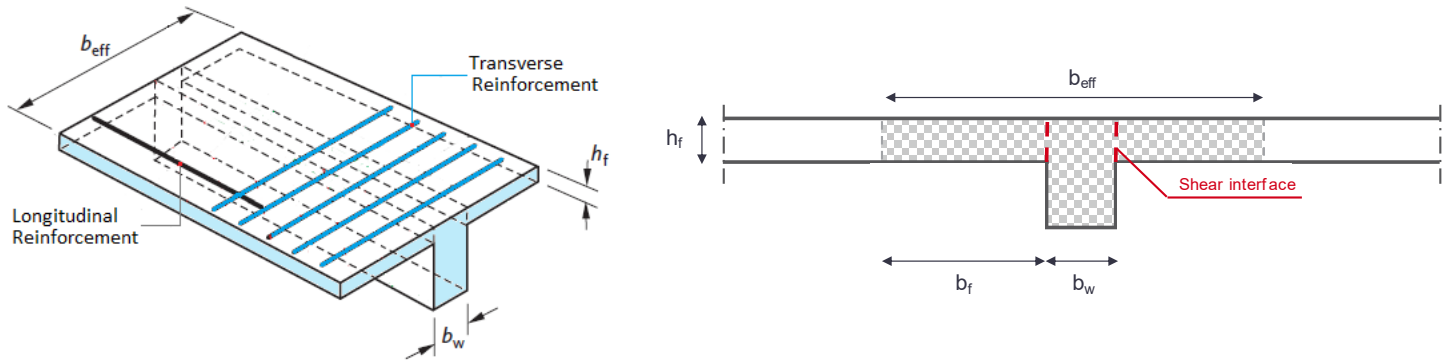


Figure L.22: Parameters for shear in web-flange interface

|                 |          |      |                   |                                                                |
|-----------------|----------|------|-------------------|----------------------------------------------------------------|
| Width of flange | $b_f$    | 360  | mm                |                                                                |
| Shear stress    | $v_{Ed}$ | 0,17 | N/mm <sup>2</sup> | $v_{Ed} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{0.9d * h_f}$     |
|                 | k        | 0,4  |                   | EN 1992-1-1/NB                                                 |
|                 | 0,17     | ≤    | 0,162             | $v_{ed} \leq k * f_{ctd}$<br>Transverse reinforcement required |

| Required transversal shear reinforcement   |            |       |                     |                                                                                                                                                    |
|--------------------------------------------|------------|-------|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
|                                            | $A_{st}/s$ | 0,002 | mm <sup>2</sup> /mm | $\frac{A_{st}}{s} = \frac{b_f}{b_{eff}} * \frac{V_{Ed}}{2 * f_{yd}} * \frac{1}{\cot\theta_f}$<br>$1,0 \leq \theta_f \leq 1,25$ for tension flanges |
| Spacing of transversal shear reinforcement | s          | 1751  | mm                  |                                                                                                                                                    |

### L.2.7 Steel beam



Figure L.23: Schematisation of the load distribution on the steel beam

The spread-out point loads from the ribs on the steel beam are schematised as a distributed load, as shown in Figure L.23. The load on the beam include the own weight of the beam and the weight of the floor elements on both sides of the beam.

| Input                                               |                   |          |                   |                                          |
|-----------------------------------------------------|-------------------|----------|-------------------|------------------------------------------|
| Dimensions                                          |                   |          |                   |                                          |
| Number of ribs                                      | n                 | 7        |                   |                                          |
| Span                                                | L                 | 6100     | mm                |                                          |
|                                                     |                   |          |                   |                                          |
| Profile properties                                  |                   |          |                   |                                          |
| RHS 200x120 / 12,5                                  |                   |          |                   | (Eurocode Applied, n.d.)                 |
| Height                                              | h                 | 200      | mm                |                                          |
| Width                                               | b                 | 120      | mm                |                                          |
| Wall thickness                                      | t                 | 12,5     | mm                |                                          |
| Outer rounding radius                               | r                 | 18,8     | mm                |                                          |
| Area                                                | A                 | 7207     | mm <sup>2</sup>   |                                          |
| Second moment of area                               | I <sub>y</sub>    | 35760000 | mm <sup>4</sup>   |                                          |
| Plastic section modulus                             | W <sub>y,pl</sub> | 455100   | mm <sup>3</sup>   |                                          |
| Weight                                              | G                 | 56,6     | kg/m              |                                          |
|                                                     |                   | 0,56     | kN/m              |                                          |
| Section classification                              | Class             | 1        |                   |                                          |
|                                                     |                   |          |                   |                                          |
| Steel properties                                    |                   |          |                   |                                          |
| S355                                                |                   |          |                   |                                          |
| Design yield stress                                 | f <sub>y</sub>    | 355      | N/mm <sup>2</sup> |                                          |
| Young's modulus                                     | E                 | 210000   | N/mm <sup>2</sup> |                                          |
|                                                     |                   |          |                   |                                          |
| Partial factor                                      | γ <sub>M0</sub>   | 1,0      |                   |                                          |
|                                                     |                   |          |                   |                                          |
| Loads                                               |                   |          |                   |                                          |
| Load from floor element on beam in a fire situation | V <sub>fi</sub>   | 13,55    | kN                |                                          |
|                                                     |                   |          |                   |                                          |
| Distributed load in a fire situation                | q <sub>fi</sub>   | 31,65    | kN/m              | $q_{ULS} = 2 * \frac{n * V_{fi}}{L} + G$ |
|                                                     |                   |          |                   |                                          |

| Load distribution                                                                         |                   |           |     |                                                                                                |
|-------------------------------------------------------------------------------------------|-------------------|-----------|-----|------------------------------------------------------------------------------------------------|
| Bending moment                                                                            | $M_{Ed}$          | 147,2     | kNm | $M_{Ed} = \frac{1}{8} q_{ULS} L^2$                                                             |
| Shear force                                                                               | $V_{Ed}$          | 96,5      | kN  | $V_{Ed} = \frac{1}{2} q_{ULS} L$                                                               |
|                                                                                           |                   |           |     |                                                                                                |
| Bending resistance                                                                        |                   |           |     |                                                                                                |
| Bending moment resistance                                                                 | $M_{Rd}$          | 100110000 | Nmm | $M_{Rd} = \frac{W_{pl} * f_y}{\gamma_{M0}}$                                                    |
|                                                                                           |                   | 100       | kNm |                                                                                                |
|                                                                                           |                   |           |     |                                                                                                |
| Required time resistance                                                                  | t                 | 60        | min |                                                                                                |
| Temperature at time t                                                                     | $\theta$          | 945       | °C  | $\theta = 20 + 345 \log(8t + 1)$                                                               |
|                                                                                           |                   |           |     |                                                                                                |
| Reduction factor for effective yield stress                                               | $k_{y\theta}$     | 0,051     |     | EN 1993-1-2                                                                                    |
| Partial factor for fire                                                                   | $\gamma_{Mfi}$    | 1,0       |     | EN 1993-1-2                                                                                    |
|                                                                                           |                   |           |     |                                                                                                |
| Bending moment resistance in a fire situation for a uniform cross-section temperature     | $M_{Rd,\theta}$   | 8,23      | kNm | $M_{Rd,\theta} = k_{y,\theta} * M_{Rd} * \frac{\gamma_{M0}}{\gamma_{m,fi}}$                    |
|                                                                                           |                   |           |     |                                                                                                |
| Unity check                                                                               | 17,80             | ≤         | 1,0 |                                                                                                |
|                                                                                           |                   |           |     |                                                                                                |
| Adaption factor for a non-uniform cross-section temperature                               | $K_1$             | 0,85      |     |                                                                                                |
| Adaption factor for a non-uniform temperature distribution over the span                  | $K_2$             | 0,85      |     |                                                                                                |
| Bending moment resistance in a fire situation for a non-uniform cross-section temperature | $M_{Rd,t,\theta}$ | 11,39     | kNm | $M_{Rd,t,\theta} = \frac{M_{Rd,\theta}}{K_1 K_2}$                                              |
|                                                                                           |                   |           |     |                                                                                                |
| Unity check                                                                               | 12,86             | ≤         | 1,0 | Also with the most favourable adaption factors, the bending moment resistance does not suffice |

## Appendix M Evaluation of new design

### M.1 Circularity assessment

#### M.1.1 Option A.ii

Table M.1: BOM Option A.ii

| Bill of Materials (BOM) |                  |           |                                       |                     |                                       |                 |                  |                 |
|-------------------------|------------------|-----------|---------------------------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product          | Layer     | Use phase [years]                     | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P0A001                  | Structural floor | Structure | 60                                    |                     | 278,0                                 | 278,0           | 41,0%            | 95,3%           |
|                         |                  |           |                                       | Reinforced concrete | 164                                   | 164             | 0,0%             | 98,9%           |
|                         |                  |           | (Twee "R" Recycling Groep B.V., n.d.) | Granulate           | 114                                   | 114             | 100%             | 90%             |
|                         |                  |           |                                       |                     |                                       |                 |                  |                 |
| P0A002                  | Top floor        | Structure | 60                                    |                     | 25,0                                  | 25              | 0,0%             | 95,0%           |
|                         |                  |           |                                       | Covering panel      | 25                                    | 25              | 0%               | 95%             |

Table M.2: BOM Option A.ii with non-recycled granulate

| Bill of Materials (BOM) |                  |           |                                       |                     |                                       |                 |                  |                 |
|-------------------------|------------------|-----------|---------------------------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product          | Layer     | Use phase [years]                     | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P0A001                  | Structural floor | Structure | 60                                    |                     | 278,0                                 | 278,0           | 0,0%             | 95,3%           |
|                         |                  |           |                                       | Reinforced concrete | 164                                   | 164             | 0,0%             | 98,9%           |
|                         |                  |           | (Twee "R" Recycling Groep B.V., n.d.) | Granulate           | 114                                   | 114             | 0%               | 90%             |
|                         |                  |           |                                       |                     |                                       |                 |                  |                 |
| P0A002                  | Top floor        | Structure | 60                                    |                     | 25,0                                  | 25              | 0,0%             | 95,0%           |
|                         |                  |           |                                       | Covering panel      | 25                                    | 25              | 0%               | 95%             |

Table M.3: MCI Option A.ii

| Material Circularity Indicator (MCI) |       |                    |      |
|--------------------------------------|-------|--------------------|------|
| P03001 Load-bearing floor            |       |                    |      |
| Material input                       |       | Utility factor     |      |
| Non-virgin materials                 | 41,0% | Layers' lifetime   | 100  |
| Virgin materials                     | 59,0% | Product's lifetime | 60   |
| Total                                | 100%  | Utility factor     | 0,60 |
|                                      |       |                    |      |
| Material output                      |       | Linear flow index  |      |
| Reusable materials                   | 95,3% | Linear flow index  | 0,32 |

|                         |        |                                       |              |
|-------------------------|--------|---------------------------------------|--------------|
| Waste material          | 4,7%   |                                       |              |
| Total                   | 100%   | <b>Material circularity indicator</b> |              |
|                         |        | Function of the utility factor        | 1,50         |
|                         |        | <b>MCI</b>                            | <b>0,522</b> |
| <b>P03002 Top floor</b> |        |                                       |              |
| <b>Material input</b>   |        | <b>Utility factor</b>                 |              |
| Non-virgin materials    | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials        | 100,0% | Product's lifetime                    | 60           |
| Total                   | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>  |        | <b>Linear flow index</b>              |              |
| Reusable materials      | 95,0%  | Linear flow index                     | 0,53         |
| Waste material          | 5,0%   |                                       |              |
| Total                   | 100%   | <b>Material circularity indicator</b> |              |
|                         |        | Function of the utility factor        | 1,50         |
|                         |        | <b>MCI</b>                            | <b>0,213</b> |

Table M.4: MCI Option A.ii with non-recycled granulate

| <b>Material Circularity Indicator (MCI)</b> |        |                                       |              |
|---------------------------------------------|--------|---------------------------------------|--------------|
| <b>P03001 Load-bearing floor</b>            |        |                                       |              |
| <b>Material input</b>                       |        | <b>Utility factor</b>                 |              |
| Non-virgin materials                        | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials                            | 100,0% | Product's lifetime                    | 60           |
| Total                                       | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>                      |        | <b>Linear flow index</b>              |              |
| Reusable materials                          | 95,3%  | Linear flow index                     | 0,52         |
| Waste material                              | 4,7%   |                                       |              |
| Total                                       | 100%   | <b>Material circularity indicator</b> |              |
|                                             |        | Function of the utility factor        | 1,50         |
|                                             |        | <b>MCI</b>                            | <b>0,214</b> |
| <b>P03002 Top floor</b>                     |        |                                       |              |
| <b>Material input</b>                       |        | <b>Utility factor</b>                 |              |
| Non-virgin materials                        | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials                            | 100,0% | Product's lifetime                    | 60           |
| Total                                       | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>                      |        | <b>Linear flow index</b>              |              |
| Reusable materials                          | 95,0%  | Linear flow index                     | 0,53         |
| Waste material                              | 5,0%   |                                       |              |
| Total                                       | 100%   | <b>Material circularity indicator</b> |              |
|                                             |        | Function of the utility factor        | 1,50         |
|                                             |        | <b>MCI</b>                            | <b>0,213</b> |

Table M.5: PCI Option A.ii

| Product Circularity Indicator (PCI)       |                                                                      |  |       |               |
|-------------------------------------------|----------------------------------------------------------------------|--|-------|---------------|
| P03001 Load-bearing floor                 |                                                                      |  |       |               |
| Disassembly factors                       |                                                                      |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of load-bearing elements                                 |  | 0,6   | 0,313         |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      |  | 0,8   | 0,418         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1     | 0,522         |
| Geometry of product edge                  | Symmetrical overlapping                                              |  | 0,8   | 0,418         |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1     | 0,522         |
| Type of connections                       | Direct connection with additional fixing devices                     |  | 0,8   | 0,418         |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          |  | 0,8   | 0,418         |
| Product circularity indicator             |                                                                      |  |       |               |
| PCI                                       | 0,432                                                                |  |       |               |
| P03002 Top floor                          |                                                                      |  |       |               |
| Disassembly factors                       |                                                                      |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Separation of functions                                              |  | 1     | 0,213         |
| Functional dependence                     | Modular zoning                                                       |  | 1     | 0,213         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1     | 0,213         |
| Geometry of product edge                  | Symmetrical overlapping                                              |  | 0,8   | 0,170         |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1     | 0,213         |
| Type of connections                       | Accessory external connection or connection system                   |  | 1     | 0,213         |
| Accessibility to fixings and intermediary | Accessible                                                           |  | 1     | 0,213         |
| Product circularity indicator             |                                                                      |  |       |               |
| PCI                                       | 0,206                                                                |  |       |               |

Table M.6: PCI Option A.ii with non-recycled granulate

| Product Circularity Indicator (PCI)       |                                                                      |  |       |               |
|-------------------------------------------|----------------------------------------------------------------------|--|-------|---------------|
| P03001 Load-bearing floor                 |                                                                      |  |       |               |
| Disassembly factors                       |                                                                      |  | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Integration of load-bearing elements                                 |  | 0,6   | 0,129         |
| Functional dependence                     | Planned interpenetrating for different solutions (overcapacity)      |  | 0,8   | 0,172         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) |  | 1     | 0,214         |
| Geometry of product edge                  | Symmetrical overlapping                                              |  | 0,8   | 0,172         |
| Standardisation of product edge           | Pre-made geometry                                                    |  | 1     | 0,214         |
| Type of connections                       | Direct connection with additional fixing devices                     |  | 0,8   | 0,172         |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          |  | 0,8   | 0,172         |
| Product circularity indicator             |                                                                      |  |       |               |
| PCI                                       | 0,178                                                                |  |       |               |

|                                           |                                                                      |       |               |
|-------------------------------------------|----------------------------------------------------------------------|-------|---------------|
| <b>P03002 Top floor</b>                   |                                                                      |       |               |
| <b>Disassembly factors</b>                |                                                                      | $F_i$ | $MCI_p * F_i$ |
| Functional separation                     | Separation of functions                                              | 1     | 0,213         |
| Functional dependence                     | Modular zoning                                                       | 1     | 0,213         |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1     | 0,213         |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8   | 0,170         |
| Standardisation of product edge           | Pre-made geometry                                                    | 1     | 0,213         |
| Type of connections                       | Accessory external connection or connection system                   | 1     | 0,213         |
| Accessibility to fixings and intermediary | Accessible                                                           | 1     | 0,213         |
| <b>Product circularity indicator</b>      |                                                                      |       |               |
| <b>PCI</b>                                | <b>0,206</b>                                                         |       |               |

Table M.7: SCI Option A.ii

| System Circularity Indicator (SCI) |              |       |       |           |           |
|------------------------------------|--------------|-------|-------|-----------|-----------|
| Product                            | Mass         | MCI   | PCI   | $MCI * M$ | $PCI * M$ |
| P0A001                             | 278,0        | 0,522 | 0,432 | 145,1     | 120,2     |
| P0A002                             | 25,0         | 0,213 | 0,206 | 5,3       | 5,2       |
|                                    |              |       |       |           |           |
| <b>SCI<sub>t</sub></b>             | <b>0,496</b> |       |       |           |           |
| <b>SCI<sub>p</sub></b>             | <b>0,414</b> |       |       |           |           |

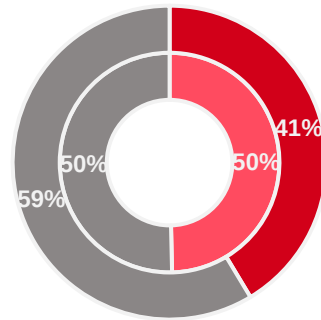
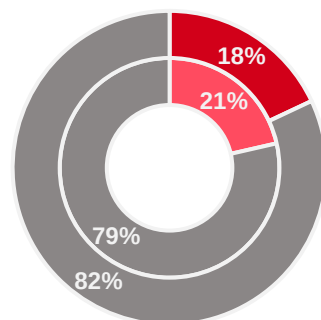


Table M.8: SCI Option A.ii with non-recycled granulate

| System Circularity Indicator (SCI) |              |       |       |           |           |
|------------------------------------|--------------|-------|-------|-----------|-----------|
| Product                            | Mass         | MCI   | PCI   | $MCI * M$ | $PCI * M$ |
| P0A001                             | 278,0        | 0,214 | 0,178 | 59,6      | 49,4      |
| P0A002                             | 25,0         | 0,213 | 0,206 | 5,3       | 5,2       |
|                                    |              |       |       |           |           |
| <b>SCI<sub>t</sub></b>             | <b>0,214</b> |       |       |           |           |
| <b>SCI<sub>p</sub></b>             | <b>0,180</b> |       |       |           |           |





### M.1.2 Option B.ii

Table M.9: BOM Option B.ii

| Bill of Materials (BOM) |                  |           |                                       |                     |                                       |                 |                  |                 |
|-------------------------|------------------|-----------|---------------------------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product          | Layer     | Use phase [years]                     | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P0A001                  | Structural floor | Structure | 60                                    |                     | 285,0                                 | 285,0           | 38,9%            | 95,4%           |
|                         |                  |           |                                       | Reinforced concrete | 174                                   | 174             | 0,0%             | 98,9%           |
|                         |                  |           | (Twee "R" Recycling Groep B.V., n.d.) | Granulate           | 111                                   | 111             | 100%             | 90%             |
| P0A002                  | Top floor        | Structure | 60                                    |                     | 25,0                                  | 25              | 0,0%             | 95,0%           |
|                         |                  |           |                                       | Covering panel      | 25                                    | 25              | 0%               | 95%             |

Table M.10: BOM Option B.ii with non-recycled granulate

| Bill of Materials (BOM) |                  |           |                                       |                     |                                       |                 |                  |                 |
|-------------------------|------------------|-----------|---------------------------------------|---------------------|---------------------------------------|-----------------|------------------|-----------------|
| Id#                     | Product          | Layer     | Use phase [years]                     | Materials           | Mass [kg/m <sup>2</sup> or m or pcs.] | Total mass [kg] | Non-virgin input | Reusable output |
| P0A001                  | Structural floor | Structure | 60                                    |                     | 285,0                                 | 285,0           | 0,0%             | 95,4%           |
|                         |                  |           |                                       | Reinforced concrete | 174                                   | 174             | 0,0%             | 98,9%           |
|                         |                  |           | (Twee "R" Recycling Groep B.V., n.d.) | Granulate           | 111                                   | 111             | 0%               | 90%             |
| P0A002                  | Top floor        | Structure | 60                                    |                     | 25,0                                  | 25              | 0,0%             | 95,0%           |
|                         |                  |           |                                       | Covering panel      | 25                                    | 25              | 0%               | 95%             |

Table M.11: MCI Option B.ii

| Material Circularity Indicator (MCI) |       |                                       |              |
|--------------------------------------|-------|---------------------------------------|--------------|
| <b>P03001 Load-bearing floor</b>     |       |                                       |              |
| <b>Material input</b>                |       | <b>Utility factor</b>                 |              |
| Non-virgin materials                 | 38,9% | Layers' lifetime                      | 100          |
| Virgin materials                     | 61,1% | Product's lifetime                    | 60           |
| Total                                | 100%  | Utility factor                        | 0,60         |
| <b>Material output</b>               |       | <b>Linear flow index</b>              |              |
| Reusable materials                   | 95,4% | Linear flow index                     | 0,33         |
| Waste material                       | 4,6%  |                                       |              |
| Total                                | 100%  | <b>Material circularity indicator</b> |              |
|                                      |       | Function of the utility factor        | 1,50         |
|                                      |       | <b>MCI</b>                            | <b>0,508</b> |

|                         |        |                                       |              |
|-------------------------|--------|---------------------------------------|--------------|
|                         |        |                                       |              |
| <b>P03002 Top floor</b> |        |                                       |              |
| <b>Material input</b>   |        | <b>Utility factor</b>                 |              |
| Non-virgin materials    | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials        | 100,0% | Product's lifetime                    | 60           |
| Total                   | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>  |        | <b>Linear flow index</b>              |              |
| Reusable materials      | 95,0%  | Linear flow index                     | 0,53         |
| Waste material          | 5,0%   |                                       |              |
| Total                   | 100%   | <b>Material circularity indicator</b> |              |
|                         |        | Function of the utility factor        | 1,50         |
|                         |        | <b>MCI</b>                            | <b>0,213</b> |

Table M.12: MCI Option B.ii with non-recycled granulate

| Material Circularity Indicator (MCI) |        |                                       |              |
|--------------------------------------|--------|---------------------------------------|--------------|
| <b>P03001 Load-bearing floor</b>     |        |                                       |              |
| <b>Material input</b>                |        | <b>Utility factor</b>                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials                     | 100,0% | Product's lifetime                    | 60           |
| Total                                | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>               |        | <b>Linear flow index</b>              |              |
| Reusable materials                   | 95,4%  | Linear flow index                     | 0,52         |
| Waste material                       | 4,6%   |                                       |              |
| Total                                | 100%   | <b>Material circularity indicator</b> |              |
|                                      |        | Function of the utility factor        | 1,50         |
|                                      |        | <b>MCI</b>                            | <b>0,216</b> |
| <b>P03002 Top floor</b>              |        |                                       |              |
| <b>Material input</b>                |        | <b>Utility factor</b>                 |              |
| Non-virgin materials                 | 0,0%   | Layers' lifetime                      | 100          |
| Virgin materials                     | 100,0% | Product's lifetime                    | 60           |
| Total                                | 100%   | Utility factor                        | 0,60         |
| <b>Material output</b>               |        | <b>Linear flow index</b>              |              |
| Reusable materials                   | 95,0%  | Linear flow index                     | 0,53         |
| Waste material                       | 5,0%   |                                       |              |
| Total                                | 100%   | <b>Material circularity indicator</b> |              |
|                                      |        | Function of the utility factor        | 1,50         |
|                                      |        | <b>MCI</b>                            | <b>0,213</b> |

Table M.13: PCI Option A.ii

| Product Circularity Indicator (PCI) |                                                                 |                      |                                        |
|-------------------------------------|-----------------------------------------------------------------|----------------------|----------------------------------------|
| <b>P03001 Load-bearing floor</b>    |                                                                 |                      |                                        |
| <b>Disassembly factors</b>          |                                                                 | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation               | Integration of load-bearing elements                            | 0,6                  | 0,305                                  |
| Functional dependence               | Planned interpenetrating for different solutions (overcapacity) | 0,8                  | 0,406                                  |

|                                           |                                                                      |                      |                                        |
|-------------------------------------------|----------------------------------------------------------------------|----------------------|----------------------------------------|
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1                    | 0,508                                  |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8                  | 0,406                                  |
| Standardisation of product edge           | Pre-made geometry                                                    | 1                    | 0,508                                  |
| Type of connections                       | Direct connection with additional fixing devices                     | 0,8                  | 0,406                                  |
| Accessibility to fixings and intermediary | Accessible with additional operation which causes no damage          | 0,8                  | 0,406                                  |
| <b>Product circularity indicator</b>      |                                                                      |                      |                                        |
| <b>PCI</b>                                | <b>0,421</b>                                                         |                      |                                        |
| <b>P03002 Top floor</b>                   |                                                                      |                      |                                        |
| <b>Disassembly factors</b>                |                                                                      | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                     | Separation of functions                                              | 1                    | 0,213                                  |
| Functional dependence                     | Modular zoning                                                       | 1                    | 0,213                                  |
| Technical life cycle / coordination       | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1                    | 0,213                                  |
| Geometry of product edge                  | Symmetrical overlapping                                              | 0,8                  | 0,170                                  |
| Standardisation of product edge           | Pre-made geometry                                                    | 1                    | 0,213                                  |
| Type of connections                       | Accessory external connection or connection system                   | 1                    | 0,213                                  |
| Accessibility to fixings and intermediary | Accessible                                                           | 1                    | 0,213                                  |
| <b>Product circularity indicator</b>      |                                                                      |                      |                                        |
| <b>PCI</b>                                | <b>0,206</b>                                                         |                      |                                        |

Table M.14: PCI Option A.ii with non-recycled granulate

| <b>Product Circularity Indicator (PCI)</b> |                                                                      |                      |                                        |
|--------------------------------------------|----------------------------------------------------------------------|----------------------|----------------------------------------|
| <b>P03001 Load-bearing floor</b>           |                                                                      |                      |                                        |
| <b>Disassembly factors</b>                 |                                                                      | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                      | Integration of load-bearing elements                                 | 0,6                  | 0,129                                  |
| Functional dependence                      | Planned interpenetrating for different solutions (overcapacity)      | 0,8                  | 0,173                                  |
| Technical life cycle / coordination        | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1                    | 0,216                                  |
| Geometry of product edge                   | Symmetrical overlapping                                              | 0,8                  | 0,173                                  |
| Standardisation of product edge            | Pre-made geometry                                                    | 1                    | 0,216                                  |
| Type of connections                        | Direct connection with additional fixing devices                     | 0,8                  | 0,173                                  |
| Accessibility to fixings and intermediary  | Accessible with additional operation which causes no damage          | 0,8                  | 0,173                                  |
| <b>Product circularity indicator</b>       |                                                                      |                      |                                        |
| <b>PCI</b>                                 | <b>0,179</b>                                                         |                      |                                        |
| <b>P03002 Top floor</b>                    |                                                                      |                      |                                        |
| <b>Disassembly factors</b>                 |                                                                      | <b>F<sub>i</sub></b> | <b>MCI<sub>p</sub> * F<sub>i</sub></b> |
| Functional separation                      | Separation of functions                                              | 1                    | 0,213                                  |
| Functional dependence                      | Modular zoning                                                       | 1                    | 0,213                                  |
| Technical life cycle / coordination        | long (1) / long (2) or short (1) / short (2) or long (1) / short (2) | 1                    | 0,213                                  |
| Geometry of product edge                   | Symmetrical overlapping                                              | 0,8                  | 0,170                                  |
| Standardisation of product edge            | Pre-made geometry                                                    | 1                    | 0,213                                  |

|                                           |                                                    |   |       |
|-------------------------------------------|----------------------------------------------------|---|-------|
| Type of connections                       | Accessory external connection or connection system | 1 | 0,213 |
| Accessibility to fixings and intermediary | Accessible                                         | 1 | 0,213 |
|                                           |                                                    |   |       |
| <b>Product circularity indicator</b>      |                                                    |   |       |
| <b>PCI</b>                                | <b>0,206</b>                                       |   |       |

Table M.15: SCI Option A.ii

| System Circularity Indicator (SCI) |              |       |       |         |         |
|------------------------------------|--------------|-------|-------|---------|---------|
| Product                            | Mass         | MCI   | PCI   | MCI * M | PCI * M |
| P0B001                             | 285,0        | 0,508 | 0,421 | 144,7   | 119,9   |
| P0B002                             | 25,0         | 0,213 | 0,206 | 5,3     | 5,2     |
|                                    |              |       |       |         |         |
| <b>SCI<sub>t</sub></b>             | <b>0,484</b> |       |       |         |         |
| <b>SCI<sub>p</sub></b>             | <b>0,404</b> |       |       |         |         |

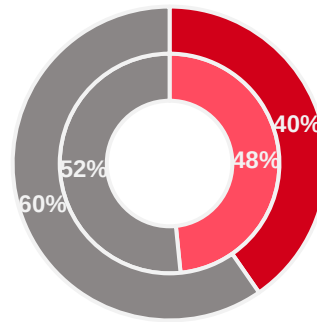
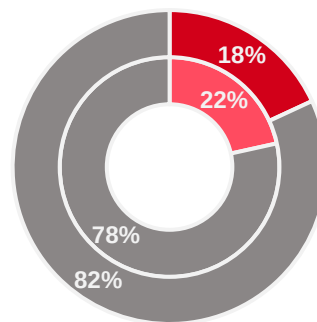


Table M.16: SCI Option A.ii with non-recycled granulate

| System Circularity Indicator (SCI) |              |       |       |         |         |
|------------------------------------|--------------|-------|-------|---------|---------|
| Product                            | Mass         | MCI   | PCI   | MCI * M | PCI * M |
| P0B001                             | 285,0        | 0,216 | 0,179 | 61,5    | 50,9    |
| P0B002                             | 25,0         | 0,213 | 0,206 | 5,3     | 5,2     |
|                                    |              |       |       |         |         |
| <b>SCI<sub>t</sub></b>             | <b>0,215</b> |       |       |         |         |
| <b>SCI<sub>p</sub></b>             | <b>0,181</b> |       |       |         |         |

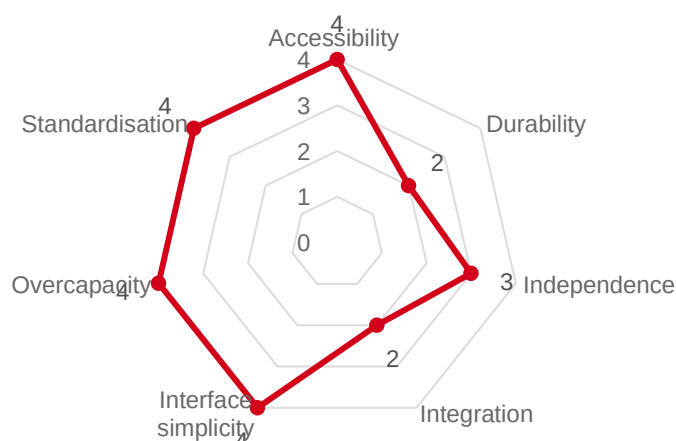


## M.2 Flexibility assessment

Table M.17: Flexibility assessment of Option A.ii and Option B.ii

| Flexibility characteristic | Weight | Input                                                                                                                                                         | Score |      | Comments                                                                                                                                                                   |
|----------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accessibility              | 0,186  | Accessible without any operation                                                                                                                              | 4     | 0,74 | The building services inside the floor can be accessed through the removable panels on top, which do not need an operation to remove                                       |
| Durability                 | 0,119  | Minimum design life ( $\geq 50$ years), requiring a modest level of maintenance                                                                               | 2     | 0,24 | Based on (Dias, 2003).                                                                                                                                                     |
| Independence               | 0,146  | Zoning of functions, few intentional interconnections                                                                                                         | 3     | 0,44 | The building services have their own space within the floor. The ribs beams contain web openings through which piping can be laid, this is an intentional interconnection. |
| Integration                | 0,093  | A part of the components that are not reasonably expected to be adapted separately are integrated into separate elements, including all or part of the system | 2     | 0,19 | All structural components are combined into one technical element and are not reasonably expected to be adapted separately.                                                |

|                      |       |                                       |   |   |      |                                                                                                                           |
|----------------------|-------|---------------------------------------|---|---|------|---------------------------------------------------------------------------------------------------------------------------|
| Interface simplicity | 0,160 | Dry connections                       |   | 4 | 0,64 | The concrete exists of one element, the connection between the concrete floor element and the panels is a dry connection. |
| Overcapacity         | 0,167 | ≥ 50% surplus                         | 4 | 3 | 0,67 | Based on the space available for the openings in the rib and the load-bearing capacity for variable loads                 |
| Standardisation      | 0,13  | Only 1 type of detail and sizing used |   | 4 | 0,52 | All the connection details are standardised and a standardised system width is used.                                      |
|                      |       |                                       |   |   | 3,43 |                                                                                                                           |



### M.3 Correlation

There is a significant positive relationship between the circularity scores and the flexibility scores of the floor systems,  $r(15)=0,68$ ,  $p<0.05$ .

Table M.18: Overview of circularity and flexibility scores

| Floor systems                                        | Circularity score | Flexibility score |
|------------------------------------------------------|-------------------|-------------------|
| Option A.ii (with recycled cover panel material)     | 0,414             | 3,43              |
| Option A.ii (with non-recycled cover panel material) | 0,180             | 3,43              |
| Option B.ii (with recycled cover panel material)     | 0,404             | 3,43              |
| Option B.ii (with non-recycled cover panel material) | 0,181             | 3,43              |
| Current design                                       | 0,128             | 1,11              |
| Piping floors                                        | 0,107             | 1,61              |
| Wing floor                                           | 0,107             | 1,44              |
| CLC multifunctional floor system                     | 0,176             | 2,92              |
| Flexvloer                                            | 0,103             | 2,33              |
| HOLCON floor                                         | 0,161             | 3,09              |
| Ides floor                                           | 0,271             | 2,60              |
| Lignatur                                             | 0,078             | 1,99              |
| Slimline                                             | 0,159             | 2,26              |
| Raised floor                                         | 0,172             | 3,00              |

|                             |        |      |
|-----------------------------|--------|------|
| <b>Suspended ceiling</b>    | 0,148  | 3,17 |
| <b>Hollow core slab</b>     | 0,088  | 1,11 |
| <b>Precast lattice slab</b> | 0,0374 | 1,11 |

Table M.19: Correlation values

| <b>Correlation</b>                     |          |             |                                    |
|----------------------------------------|----------|-------------|------------------------------------|
| <b>Pearson correlation coefficient</b> | r        | 0,676468    | <i>Moderately high correlation</i> |
| <b>Significance level</b>              | $\alpha$ | 0,05        |                                    |
| <b>Significance</b>                    | p        | 0,002865183 | <i>Significant</i>                 |