QUANTIFYING DEMOUNTABILITY OF AN EXISTING OFFICE BUILDING IN AMSTERDAM

O.R.J. Snethlage
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

ABSTRACT

This paper will investigate how an existing office building can be transformed into a residential building in a demountable way. Firstly, an overview will be provided of existing demountability quantification methods. Secondly, a case study will be presented with connection details of an office building; De Knip in Amsterdam Sloterdijk, a building that is initially not designed to be demountable. The case study will be analyzed by two existing demountability quantification tools. Finally, the relation between demountability and the functional change from an office- to a residential building will be investigated on the basis of technical and architectural aspects (appendix 5a,b,c). In this paper the quantification of the demountable components of the building skin- & load bearing structure will be the focus points.

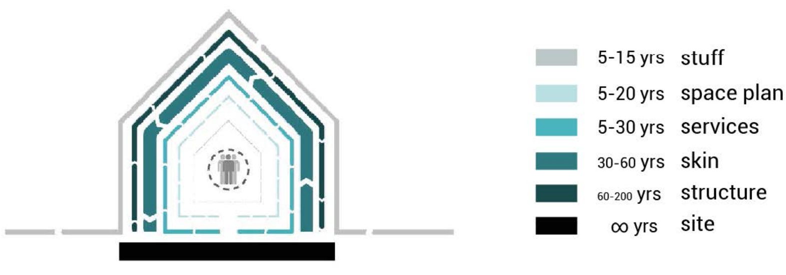
Keywords: *ADAPTABILITY, QUANTIFYING DEMOUNTABILITY, BUILDING SKIN, BUILDING STRUCTURE, OFFICE TO RESIDENTIAL TRANSFORMATION.*

I. INTRODUCTION

1.1. Adaptability

Buildings are complex products. They can be viewed as a unique merge of resources and requirements that involve design, building methods and operational complexities. Architect Stewart Brand visualizes a building as a range of 'shearing' layers that change at different durations (Figure 1). More connections that take place between the different layers, generate an increase in difficulty of adaptation and cost. (Robert Schimidt III, 2016)

Figure 1. Shearing layer concept by Steward Brand.



Today's rooms and spaces in buildings are still classified with specific functions, using prescribed space dimensions from building regulations that as a result accommodate the layout of the furniture, and subsequently defines today's buildings by their function. (Till, 2009) Despite the building industry's fixation on the static object, Tsukamoto and Kaijima suggest that a building should be perceived as a dynamic commodity that can be changed through shifting demands in time throughout the use of a building (Tsukamoto and Kaijima, 2010). The future of a building may not be fit for purpose anymore, resulting ultimately in falling out of use or having to be demolished when they cannot be adapted in a cost effective way. The use of space in buildings can be viewed as an ongoing process, a sequence of events that are ongoingly reformulated through its use or habitation – 'society in built form' (Lerup, 1977). The discrepancy between the inherent encounter of use and space can therefore result in an imbalance between supply and demand of the intended use of a building. By maximizing the life span of a building, a place can be provided for the developing needs of the community (Robert Schimidt III, 2016). This paper will investigate how an existing office building can be transformed into a residential building, and evaluate to what extend adaptability can be incorporated.

1.2. Relevance

The reason to develop more buildings that are adaptable is based on the premise that adaptable buildings are simpler to change during their existence, which additionally has benefits, being; reducing disruptions to users of the building, lessening the cost of adaptation and finally making it easier to sell or rent out the building.
The type of connections and assembly processes can make it very challenging to disassemble an object and separate the materials for reuse purposes (Shetty, 2015).
Adaptability can consequently be seen as an instrument to increase the lifespan of our built environment. The increasing understanding of the embodied energy in buildings when being constructed is an argument for the understanding that the most sustainable building, is the one that already exists (Robert Schimidt III, 2016).
Additionally, the build environment in 2016 was the biggest waste sector and accountable for 23,5% of all waste production in the Netherlands (CBS, 2019). The traditional building methods we use, like building with concrete and steel, generate a great amount of emissions that have a negative impact on our environment. The material resources we use to construct the buildings on our planet, are often used in a singular way. If the life cycle after the intended use of a material is not taken into consideration, materials often end up in linear waste streams, resulting in a depletion of materials and larger CO2 emissions than necessary.
Lastly, there is a housing shortage in the Netherlands. Estimations are that between 2020 and 2030 a total of 845.000 dwellings are needed to be built to accommodate the housing demand (Rijksoverheid, 2020). It is therefore of relevance to examine how this investigation can contribute to the further development of buildings in order to increase the housing stock.

1.3. Objective & Research Focus

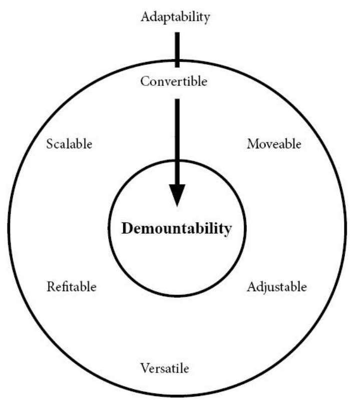
Accommodating the evolving demands in a context through an adaptable design can still be interpreted in different ways. This paragraph will explain what the focus in the broad spectrum of adaptability in this paper will be and subsequently its relevance.
According to the research of R. Schmidt III & S. Austin, the term 'adaptability' in architecture can be distinguished in six different typologies (figure 1). Each typology can assist and clarify the goal of the design outcome. (Robert Schimidt III, 2016)

Figure 2. Typologies of adaptability.

Adjustable	**Versatile**	**Refitable**	**Scalable**	***Convertible***	**Movable**
Change of Task	Change of Space	Change of Performance	Change of Size	**Change of Use**	Change of Location

Convertibility indicates to a change in use, that is caused by changes on the demand side, for example in the market, ownership, occupancy or social demand. Although these changes were not envisioned in the original designs, many buildings are converted to accommodate new functions (Robert Schimidt III, 2016). Convertibility therefore focuses on the maximization of the longevity of a building in a broad sense and is accordingly chosen as a focus in the research. Whether numerous conversions can be allowed for, is depended on the positioning and capacity of different physical elements (e.g. floor loading, acoustics, services, fire design and circulation).

Figure 3. Adaptability through demountability.



In order to ensure that materials will be reused, Chong et all. stated that it is the task of the designers to be at the frontline of this endeavor and stresses the importance of design for disassembly. They address the lack of quantitative methods in order to measure the benefits of demounting and recycling of buildings and materials. This results in an oversimplifications of the ways to address the reuse of materials and measuring cost and benefits cannot be done efficiently (W.K. Chong, 2010). It is therefore relevant to fill the gap of information on demountable quantification methods.

1.4. Research questions

There exist already a quite extensive documentation on the topic of demountability. However, the literature provides in most cases a generic implication towards the demountability topic. To ensure the usage of the quantification of demountability and to find practical implication for architects and designers, this paper is divided into three sections. First, this research will start by providing an overview of various existing demountability measuring tools available. Second, a case study will be conducted on the building De Knip in Amsterdam with a selection of the demountability measurement tools to investigate the applicability of the tools on a building that is not been initially designed for demountable purposes. The demountability of different connection details of the building will as a result be quantified. Third, there will be investigated how useful these results are to transform the building from an office to residential function. The first two sub research questions will be of a generic nature, while the last sub research question aims at the specific possibilities for the building De Knip to make this functional transition.

1.5. Main research question

How to improve the demountability of existing office buildings by using designed for disassembly components?

1.6. Sub research questions

1. How do the current demountability measuring tools measure demountability?
2. To what extend are the currently used demountability measuring tools applicable on existing office buildings that are not initially designed for demountable purposes? (De Knip)
3. How useful are the results from using the demountability tools on the Knip, to transform the building from an office to a residential function? (for architects)

II. OVERVIEW OF DEMOUNTABILITY MEASURING TOOLS

In order to improve the demountability of existing buildings it is necessary to use measure instruments that are able to quantify the extent of their current demountability level. The tools that will be analyzed to investigate the current demountability level of the building 'De Knip' are shown in Figure 4.

Figure 4. Demountability measuring tools.

Measuring tool 1	Measuring tool 2	Measuring tool 3
Alba Concepts	DFD - Rating factors	Measuring circularity
Developer: Alba Concepts, Dutch Green Building Council, Rijksdienst voor Ondernemend Nederland, W/E Ad, Transitieagenda Circulaire Bouweconomie	Developer: Devdas Shetty & Ahad Ali.	Developer: Platform CB'23

A building is a composition of complex materials and products that can be measured at various levels. The different levels indicate the complexity of a building component. By making the different levels specific, it is possible to properly evaluate the desired level of demountability (Alba Concepts, 2019). In the building sector there are several methods available to define these buildings levels. In the Dutch building Industry the NL/SfB & STABU2 methods are used. The NL/SfB classifies and categorizes building products to determine building levels. The STABU2 also classifies and categorizes building products but on a more specific bases (Vliet, 2018) (Figure 5).
This paper aims to measure demountability as specific as possible and is therefore set to level 5. The level of measurement is determined on the availability of archival documentation and technical drawings.

Figure 5. Different building levels. (Vliet, 2018) Adapted by Alba Concepts.

Level	Source	Adopted Definition	Example Description
0.	Layers of Brand	Building layers	Space plan
1.	NL/SfB (2 digit coding)	System level	Interior wall
2.	NL/SfB (3 digit coding)	Element group level	Non-structural
3.	NL/SfB (4 digit coding)	Element level	Fixed partition wall
4.	NL/SfB (6 digit coding)	Product level	Metal stud wall, plasterboard
5.	STABU2 (specification group)	Component level	Plasterboard
6.	STABU2 (specification group)	Material level	Plasterboard
7.		Raw material	Gypsum

2.1. Alba Concepts

Objects in buildings are often connected to one or several other objects. To ensure that the determination of the demountability will not result in a unnecessarily complex calculation of connections between objects, the decisive connection in this tool is demarcated as the connection between the object and mother object that has a supporting function. This connection results in a demountability-index. An example of this connection approach can be a window frame (child) and a structural wall (mother). This connection is assessed by the connection type, -accessibility, integration, and the interference of other objects (Alba Concepts, 2019). The scoring for each of these four connection assessment types can be found in appendix 6a. The demountable measuring method by Alba Concepts consists of three aspects regarding demountability; the process- , technical- and financial aspects. The certainty that objects are physically demountable is the central focus point in this research. Therefore the financial- and process aspect of the tool will be left out.

2.2. DFD - Rating factors

The DFD tool based on rating factors is developed for engineer designers for productively analyzing the demountability of assemblies or products in an automated way. Additionally the tool is aimed to incorporate the disassembly aspect of the design process and make it more financially accessible for design companies. The analysis of disassembling parameters are focused on the practical side of the disassembly. The rating factors which are used contain; the accessibility of a component, the tools that are required, component damage, reusability, removability, recyclability and the time required to disassemble the component (Shetty & Ali, 2015). Each parameter is rated given a score from 0 (lowest) to 9 (highest). An explanation of the scoring for each parameter can be found in appendix 6b. The tool includes Design for disassembly (DFD) and Design for assembly methods (DFA). The latter will be left out of this research.

2.3. Measuring circularity

The measuring tool by Platform CB'23 concentrates on the generic contribution to preserve and efficiently use materials in the building built environment. The tool aims to accomplish a supporting method to implement circular quantification methods in the construction process. The input and output of the tool regarding the quantification of the demountability of a building is, in this case, only based on the initial weight (Kg) of a building component and the reusable weight (Kg) respectively (Platform CB'23, 2019). Both input and output parameters are difficult to determine for every component in a building and are, as a result, a time consuming endeavor since not all the data of the specific volume and material properties of a building component are available. Due to the generic nature and likely unavailability of resources and information, this tool has not been chosen to use in this research.

III. DEMOUNTABILITY IN EXISTING OFFICE BUILDING CONNECTIONS

In this paragraph will be investigated how the previously selected demountability measuring tools apply to a case study with no intention of being demountable. The reason is to generate insights in the applicability of the measuring tools for a case study in the existing build environment. 3D models of the connections (details) that have been generated of the building(Appendix 1a,b,c,d,e & 2a,b,c,d) provide more insight on how the demountability tools are applied. The 3D models are based on archival drawings from the municipality of Amsterdam.

The building De Knip was chosen for this investigation due to the two different building typologies; a high rise building (80m) and a low rise building (17m). The high and low rise parts of the building differ in their material usage for the façade, aluminum panels and naturals stone cladding respectively. The difference in detail for the façade of the high and low rise parts of the building also accounts for the main load bearing structure. The multitude of different detailing used in De Knip require a different judgment to determine the demountability. (Appendix 1a & 2a)

The first aim of the application of the demountability tools was to make a calculation for De Knip as a whole. This calculation was executed for the both the building- skin and structure. A second subdivision was made for the calculation between the high rise and low rise part of the building. The parameters in the demountability measuring tools that are used to evaluate the demountability are; Tool1: Connection type, Connection access, Element intercrossing, Element enclosure; Tool2; Access rating, Tool rating, Task/Damage rating, Re-use rating, Removal rating, Recyclability (material) rating. The results of the demountability quantification of the connection case studies can be found in appendix 3 & 4. A description for every evaluation parameter is further elaborated in appendix 6.

3.1. Building as a whole

The building skin of the low rise and high rise show a similar build up but have different materialization finishes. Both building skins consist of prefabricated concrete elements as a main load bearing structure and are insulated with 80mm of thermal insulation. The high rise is finished by aluminum facade panels that are bolted to a supporting frame (appendix 1c). For the low rise a natural stone cladding is used as a finishing material. The latter make use of a steel supporting system similar to the high rise part. However, the natural stone panels are glued with an epoxy glue to the supporting structure resulting in a lower demountability score.

Both the structure for the high rise and low rise parts of the building score 0% for respectively six and five parameters of the demountability measuring tools (appendix 4a & 4c). The primary load bearing structure consists of concrete elements and connections that are connected by steel bar reinforcement that result in a low demountability score.

3.2. Building categories

The results from the overall demountability scores for the structure and building skin of De Knip give a generic indication of its demountability. To be able to further elaborate on the construction, the results of the building skin are split up in the categories; Roof, Facade and Plinth. The three different categories show a different approach related to their function and materialization. The measuring tool of Alba Concepts and DFD rating factors include a parameter for the access regarding demountability. The accessibility score for both tools focuses on the connection access and approach area respectively. Overall the parameters Connection type and Element enclosure score the lowest. A 35% score indicates the average scores of all related components for the specified category. The Removal parameter, indicating the damage done to adjacent parts of the assembly on removal, is the overall highest scoring parameter. Connection access (ToV) and Task/damage parameters scoring closest to the average of the overall calculation.

The selected demountability measuring tools make it possible to quantify the demountability for the various components of the building. However, the calculation is depended on the availability of technical drawings and written documentation of applied materials and sometimes can lack the amount of information needed to quantify the demountability of building components.

After quantifying the demountability and evaluation of the case studies, the demountability measuring tools also show their limitations. The demountability scores give a clear indication of the relationship between two components. However, how a component relates to the entire assembly, is not incorporated with regards to its structural capacity. The strength, stiffness and stability of the entire building can be affected when a component is demounted, and therefore needs to be further investigated.

IV. DEMOUNTABILITY IN CHANGE OF USE

To reflect on the usability of the demountability measuring tool used in the case studies, this last chapter will explore the link between demountability and the functional transformation from an office to a residential building. The demand for living requires different design criteria for a residential building than that for a work space in an office. The design criteria of a building can be a far stretching, multitude of requirements. These can range from; fire safety, context integration, indoor climate, materialization to social integration etc. To give an answer to the question how useful the results from using demountability measuring tools on the building De Knip are, to transform the building from an office to a residential function, five evaluation parameters are chosen with regard to the technical (performance) and architectural (usability) of the building.

4.1. Technical relation

The technical evaluation parameters relate to the thermal-, daylight- and acoustical performance of the building. It has to be mentioned that the De Knip was constructed in 1994 and designed along the regulations of its time. The performance standards of buildings that have been adopted in building-codes and regulations over the past three decades have been increased to facilitate higher comfort levels and optimized energy usage. The building De Knip does not meet the performance standards of today as can be seen in appendix 5a. The 80mm insulation meets the building code requirement of a 2,5 m2K/W that was regulated in 1992. This 80mm insulation is used all over the skin of the high- and low rise of the building does not meets the required Rc of today (appendix 5a). The acoustical insulation, regarding the noise reduction from outside, is provided by both the building skin and the load bearing structure. The regulatory changes regarding the allowed noise on the inside of the building from outside (NEN5077) increased by 2dB since the regulations of 1992 (appendix 5a). Daylight enters the building through the double glazed aluminium window frames, which are mounted to the prefabricated concrete facade elements for the low- and high rise parts of the building. The prefabricated structural elements are the crucial factor to allow daylight in the building. The demountability extend of the building with regard to all three technical aspects (thermal-, daylight- and acoustical performance) result in the structure being the most dominant factor. Increasing the demountability of the structure, especially that of the facade elements, would improve the ease of adaptation of future changes to the facade.

Safety and security (infiltration by unwanted people in the building) need to be taken into consideration when the building is very demountable. Safety also needs to be guaranteed in order to demount building elements. The ease in which a building element can be demounted is determined by the access of the connection as well as the workable free space of the surroundings. This applies for the possible damages to a component as well as for the person who executes the disassembly.

4.2. Architectural relation

Two architectural aspects that will be evaluated on the basis of demountability to allow for the change in use from an office to a residential function are the outdoor space and access routing. The access typologies of the access routing defined by (Leupen & Mooij, 2011) will be used as evaluation parameters (appendix 5c). From these results a clear distinction can be made between the demountable capability and access routing through the building (corridor) and along the building (balcony). The free column structure scores very low on the demountable capacity but allows for an almost free floor plan layout, making internal routing possible. This does not count for the vertical transportation cores which are all connected through reinforced concrete connection types. The access from the street level shows the same limitations as that of the balcony access typology. The concrete prefab facade elements make it difficult to create an access through the plinth, despite the relatively high scoring demountable skin for this part of the building. The other architectural aspect in relation to the outdoor spaces show similar results for when creating an external outdoor space on the facade or at the ground floor level as the access routing (appendix 5b). It is possible to create an internal outdoor space (e.g. loggia) within the existing facade structure. However, the fixed placement of the windows throughout the whole facade of the building leave no room for dimension adjustments in the design.

V. CONCLUSIONS & DISCUSSION

The goal of this research was to investigate the relation between demountability of an existing office building and the functional change from an office to a residential building. There can be concluded that the used demountability measuring tools gave a good insight in the demountable capacity of De Knip on the specified component level. The results indicate a direction for architects/designers on which parameters the most progress can be made towards a higher demountabilty rating. However, during the development of newly architectural and technical design detailing to accommodate a residential function, a new iteration of the demountability calculation required.

It would be advised to make a separation between the structure and building skin when using the demountability quantification methods. The more the building layers are connected, the higher the difficulty of adaptation. The low demountability scoring structure for both the low and high rise turned out to have the highest ascendency. The higher specification of the connections between components results in an exponential increase in time investment to make the calculation. The amount of calculations from the element level (e.g. fixed partition wall) to the product level (e.g. metal- stud wall, plasterboard etc.) grow exponentially since the element consist of multiple products. Additionally, quantifying the demountability of a building highly depends on the available data that can be acquired, since the availability of data on lower levels is often more scares. To rule out a very large time investment for the demountability calculation, it is essential to determine the goal of the demountability upfront.

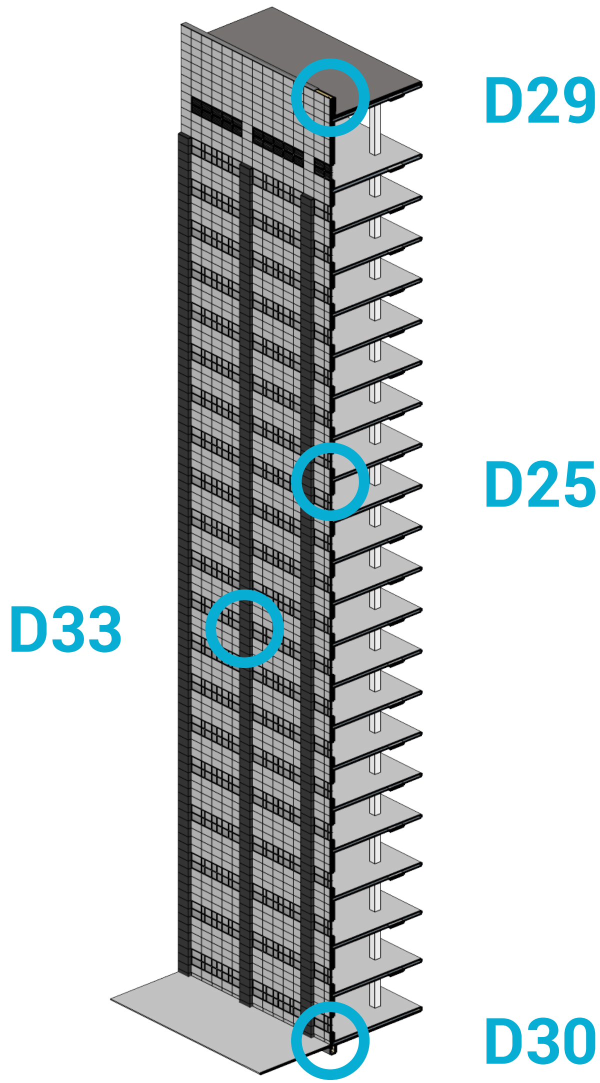
The low rise part of the building De Knip scores lower than the high rise part on the subject of demountability. The main cause for this is the structural difference and materialisation of the facades, as well as the analyzed parameters; connection type and element enclosure. Since the primary load bearing elements in the low rise part of the building have a more prominent function than the high rise part, it will have an effect on the possible access routing and outdoor spaces to enable the residential function. Designing a building for a specific use without taking in consideration the demountable aspect of building elements and products has a high effect on the future possibilities for change of use.

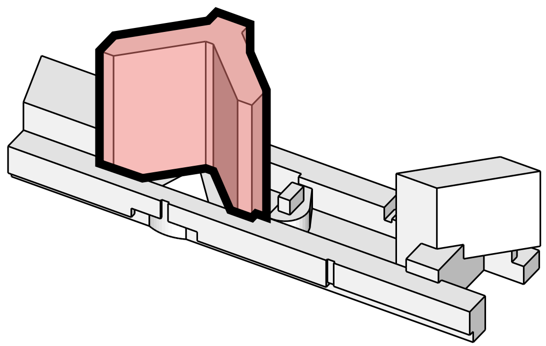
References

1. Alba Concepts. (2019, November). *Circular Buildings - Meetmethodiek Losmaakbaarheid*. Alba Concepts.
2. Platform CB'23. (2019). *Kernmethode voor het meten van circulariteit in de bouw.* Platform CB'23.
3. CBS. (2019, November 4). *Meeste afval en hergebruik materialen in bouwsector.* Retrieved on October 30, 2021, from cbs.nl: https://www.cbs.nl/nl-nl/nieuws/2019/45/meeste-afval-en-hergebruik-materialen-in-bouwsector
4. Diederen, A. (2010). *Global Resource Depletion, Managed Austerity and the Elements of Hope.*
5. Guy, B. Ciarimboli, N. (2005). *Design for disassembly in the buildenvironment*: a guide to closed-loop design and building. Seattle.
6. Habraken, J. (1961). *De dragers en de mensen*: het einde van de massawoningbouw. Eindhoven: Stichting Architecten Research.
7. Lerup, L. (1977). *Building the Unfinished* - Archietecture and Human Action. Beverly Hills: Sage.
8. Leupen, B. Mooij, H. (2011). *Het ontwerpen van woningen*. Een handboek. NAi Uitgevers.
9. Pianoo. (2019). *Handreiking Losmaakbaarheid*. Pianoo Expertise Centrum Aanbesteden.
10. Rijksoverheid. (2020, Juni 15). *Staat van de woningmarkt 2020.* Retrieved on Maart 10, 2021, from Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2020/06/15/staat-van-de-woningmarkt-2020
11. Robert Schimidt III, S. A. (2016). *Adaptable Architecture Theory and Practice*. London: Routledge - Taylor & Francis Group.
12. Shetty, D. and Ali, A. (2015). *A new design tool for DFA/DFD based on rating factors*. Emeral Group Publishing Limited.
13. Till, J. (2009). *Architecture Depends*. Cambridge, MA: MIT Press.
14. Tsukamoto, Y. and Kaijima. M. (2010). *Behaviorology*. New York: Rizzoli.
15. Vliet, M (2018). *Disassembling the steps towards building circularity*. Eindhoven University of Technology.
16. W.K. Chong, I. S. (2010). *Sustainable Recycling Approach*: An Understanding of Designers' and Contractor's Recycling Responsibilities. University of Kansas.

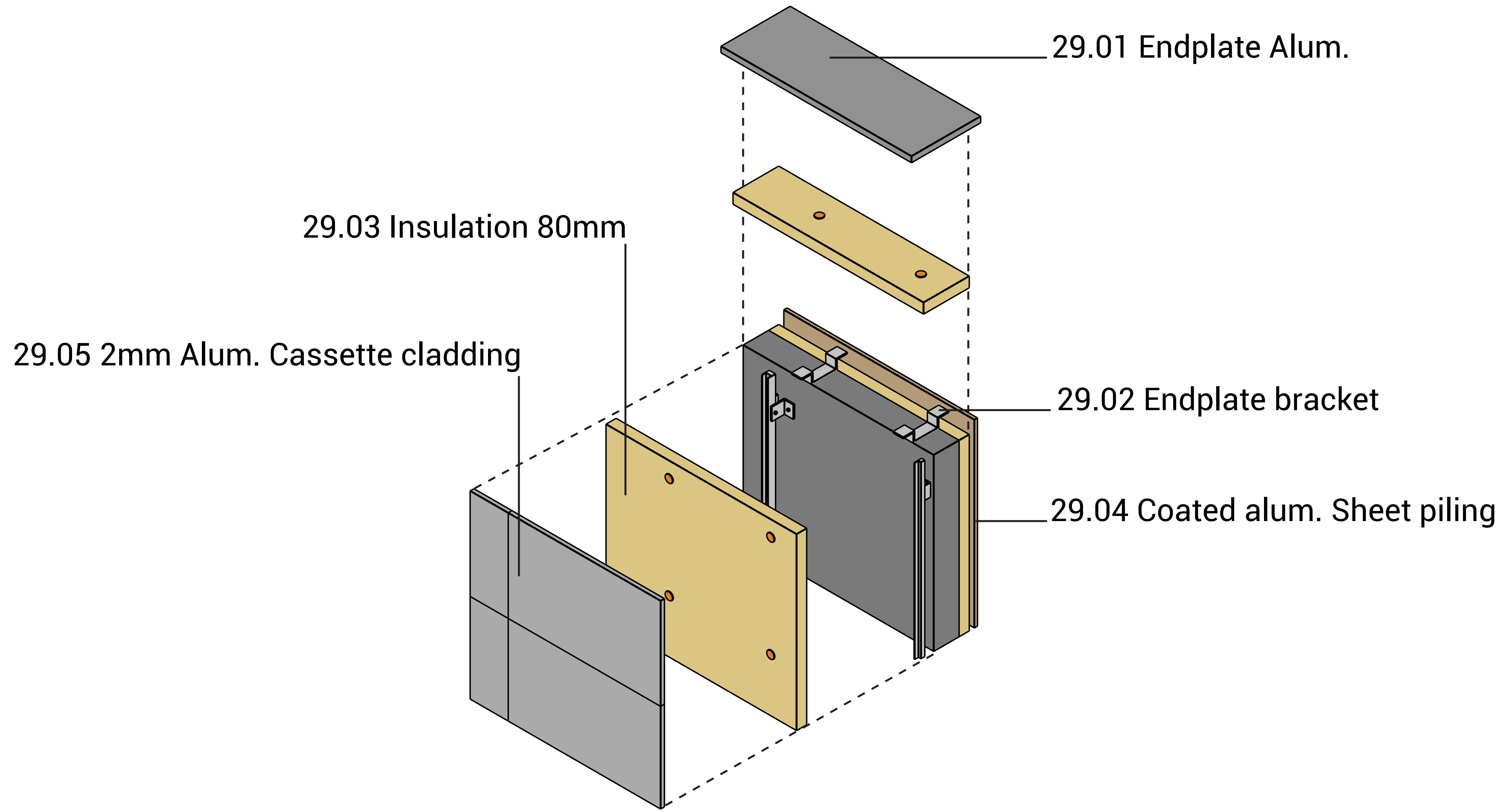
Apendix 1a.

DE KNIP - HIGH RISE



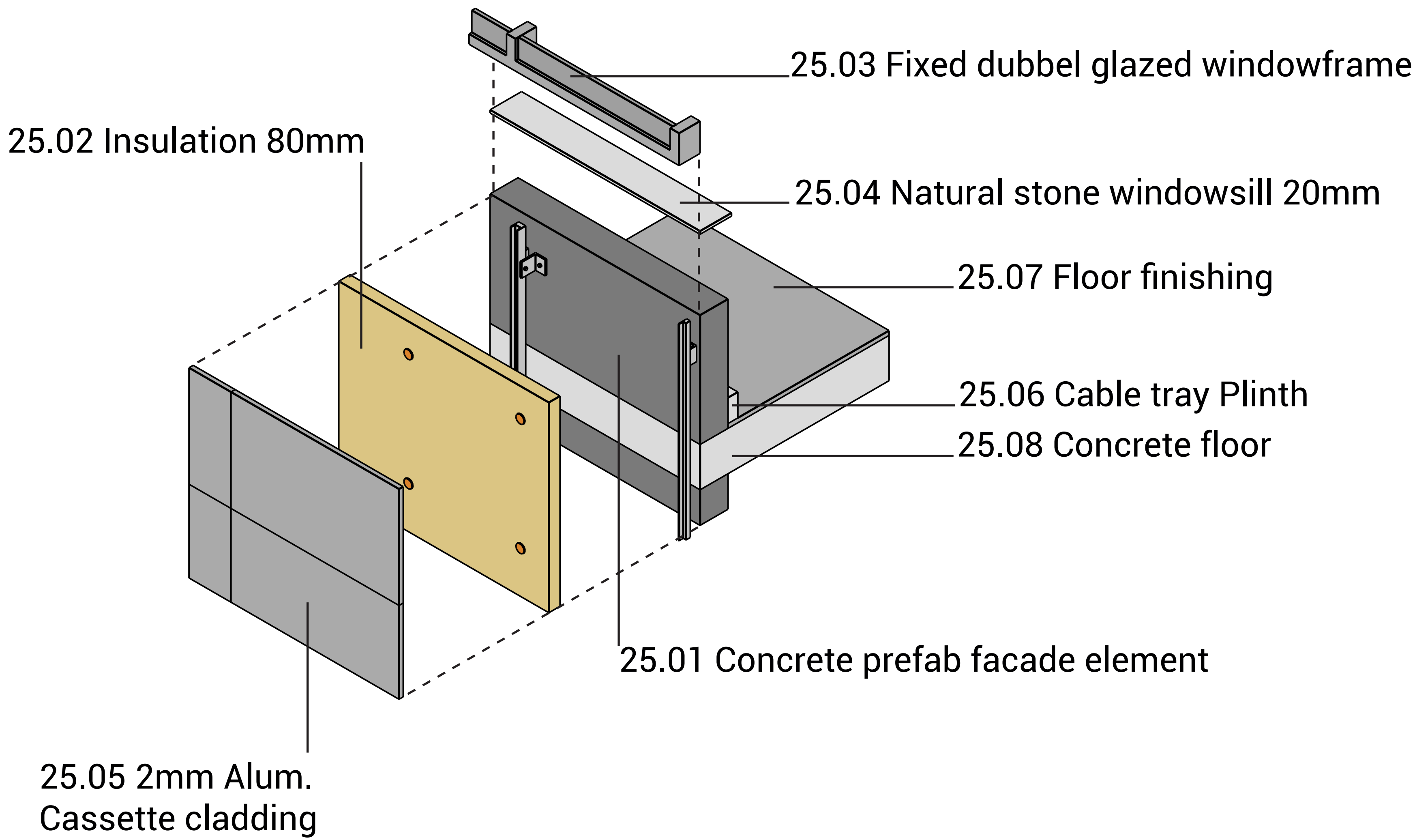


D29



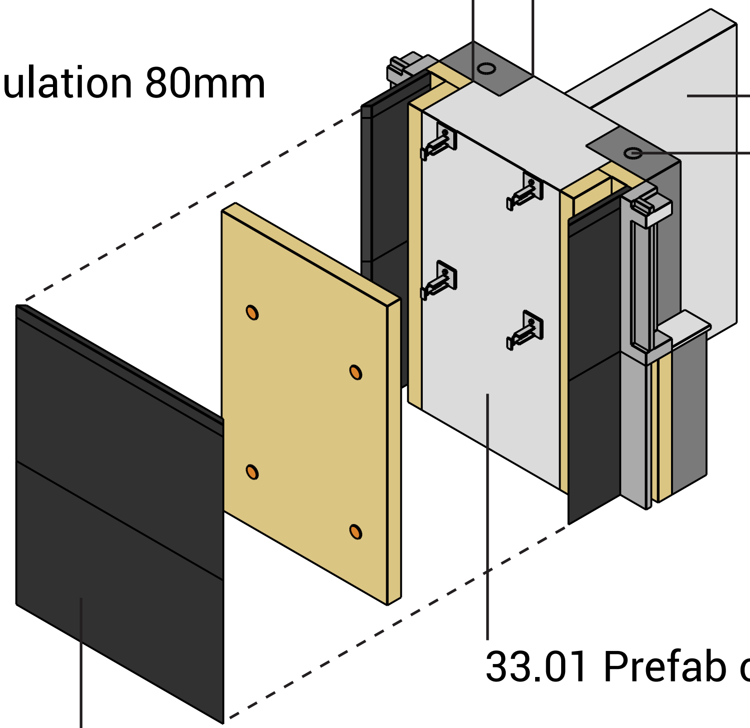
29.01 Endplate Alum.
29.03 Insulation 80mm
29.05 2mm Alum. Cassette cladding
29.02 Endplate bracket
29.04 Coated alum. Sheet piling

D25


25.03 Fixed dubbel glazed windowframe
25.02 Insulation 80mm
25.04 Natural stone windowsill 20mm
25.07 Floor finishing
25.06 Cable tray Plinth
25.08 Concrete floor
25.01 Concrete prefab facade element
25.05 2mm Alum.
Cassette cladding

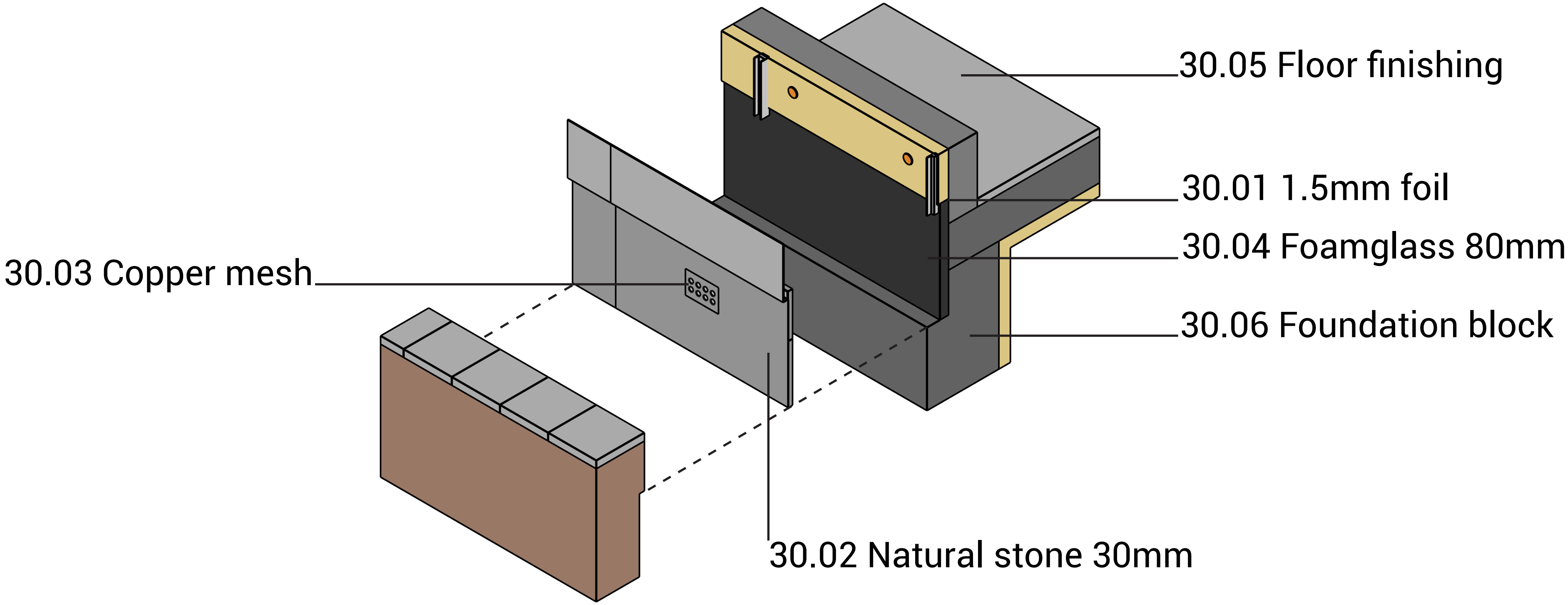
Apendix 1d.

D33



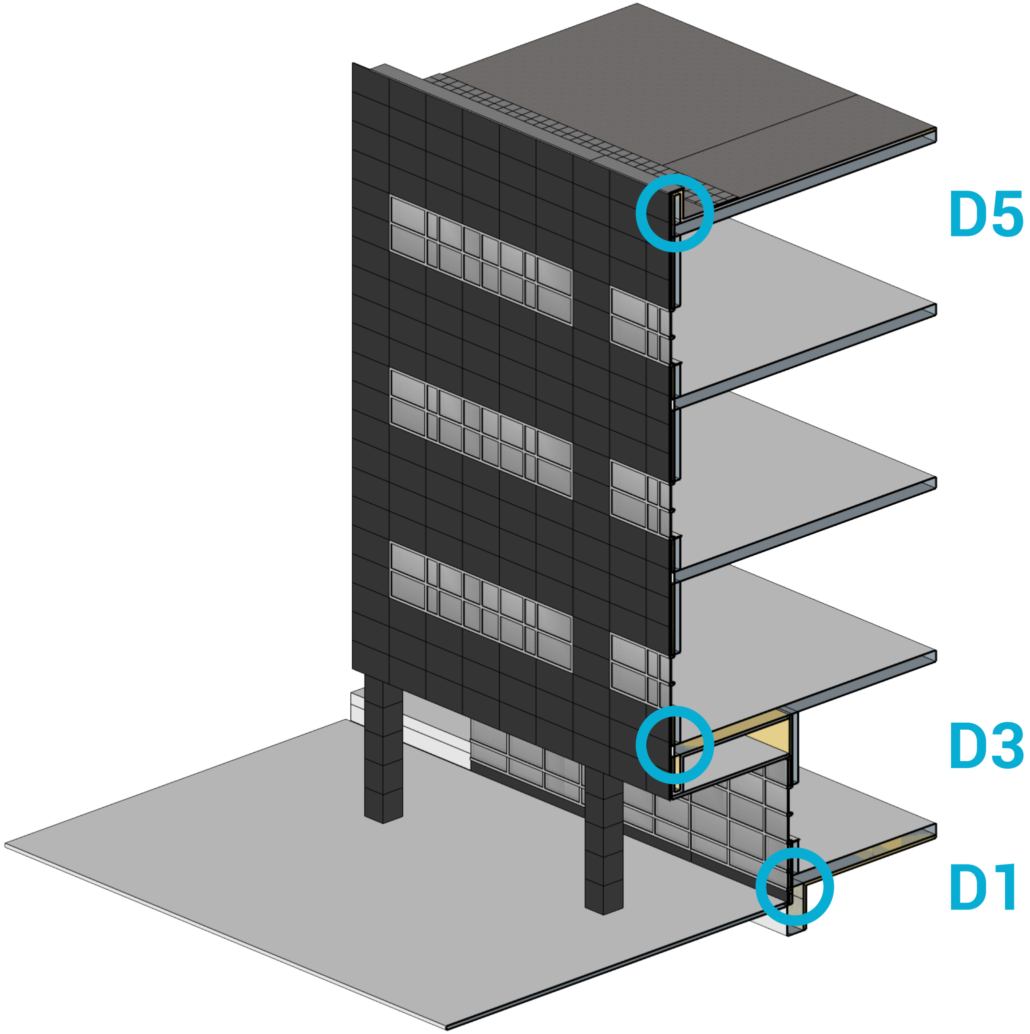
Apendix 1e.

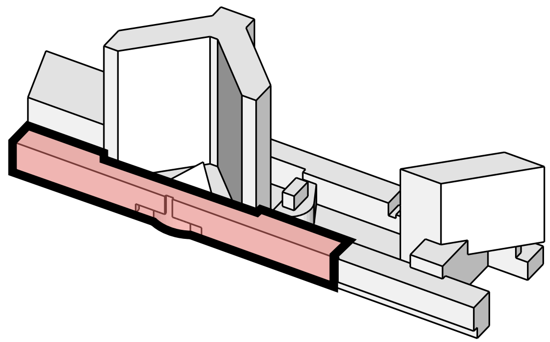
D30



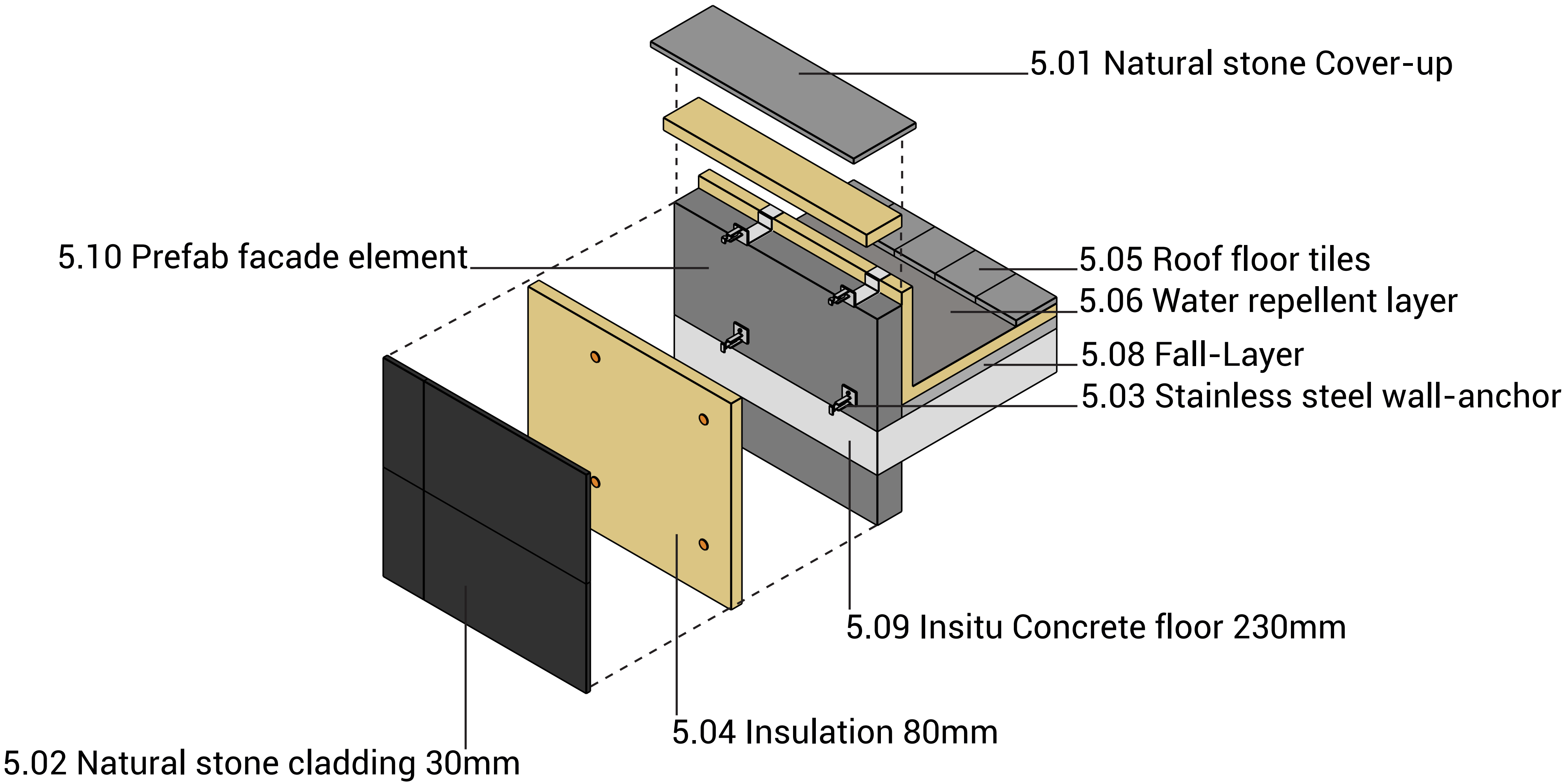
Apendix 2a.

DE KNIP - LOW RISE

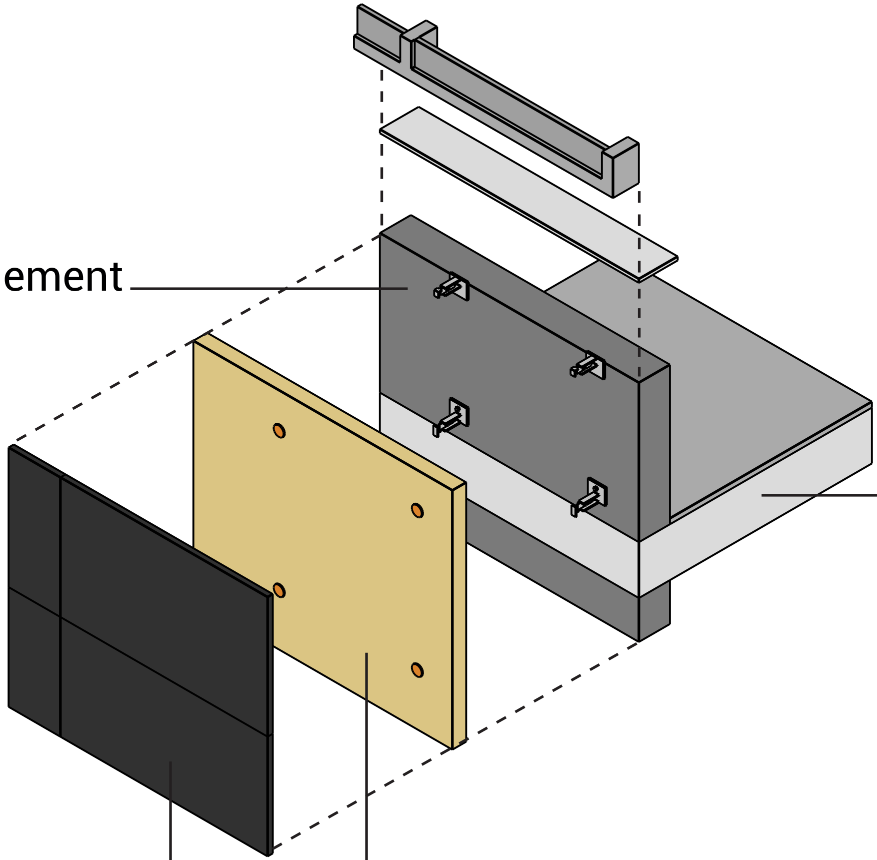




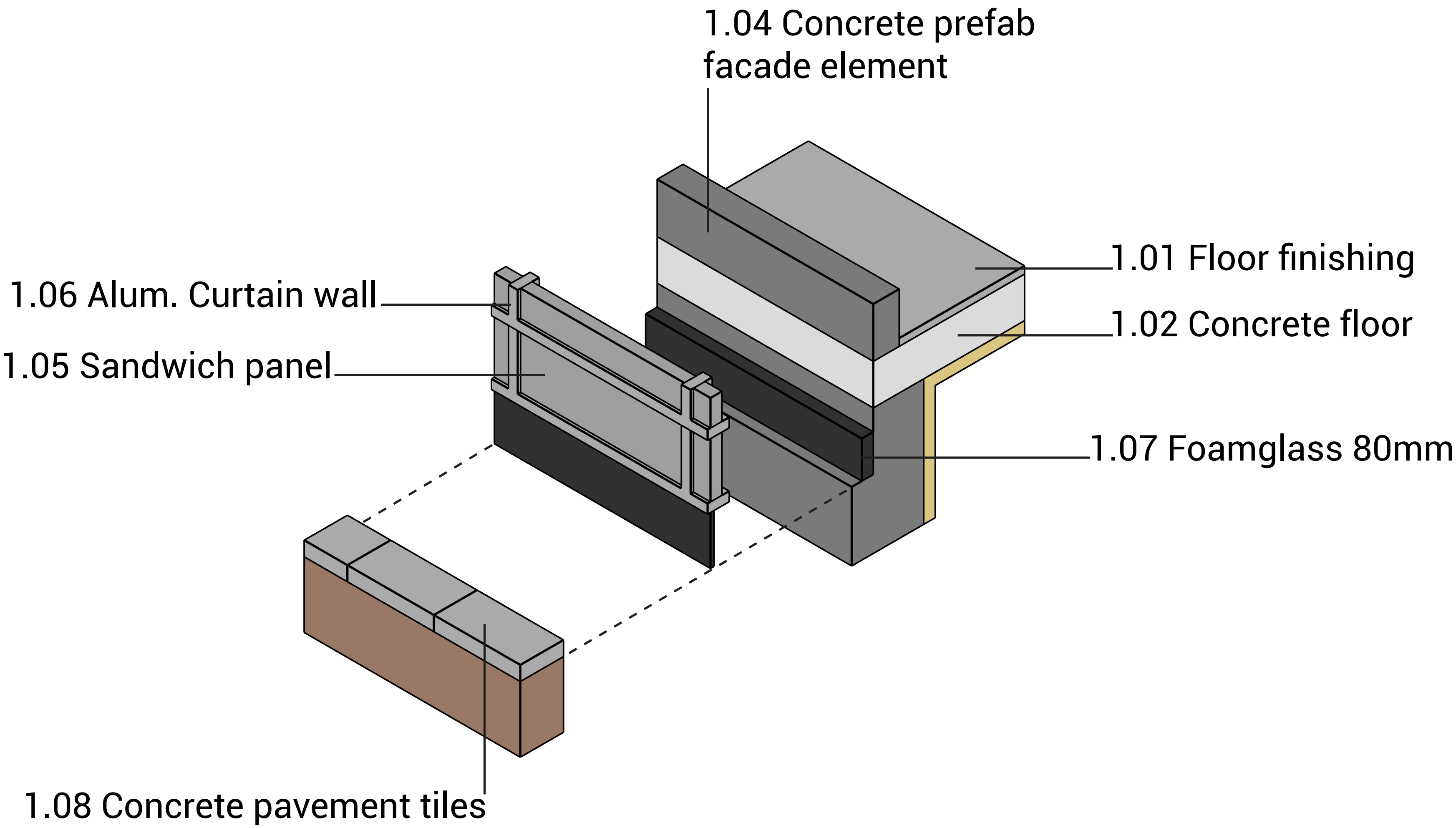
D5


5.01 Natural stone Cover-up
5.10 Prefab facade element
5.05 Roof floor tiles
5.06 Water repellent layer
5.08 Fall-Layer
5.03 Stainless steel wall-anchor
5.09 Insitu Concrete floor 230mm
5.04 Insulation 80mm
5.02 Natural stone cladding 30mm

D3


3.01 Prefab facade element
3.02 Insitu Concrete floor 230mm
3.03 Insulation Inside 80mm
3.05 Natural stone cladding 30mm (column)

D1


1.04 Concrete prefab facade element
1.01 Floor finishing
1.06 Alum. Curtain wall
1.02 Concrete floor
1.05 Sandwich panel
1.07 Foamglass 80mm
1.08 Concrete pavement tiles

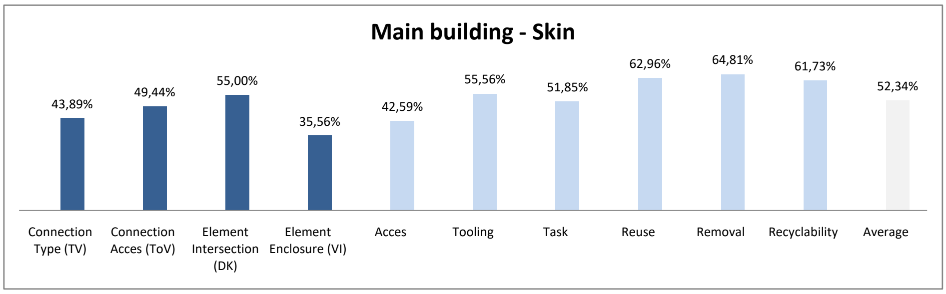
Apendix 3a.

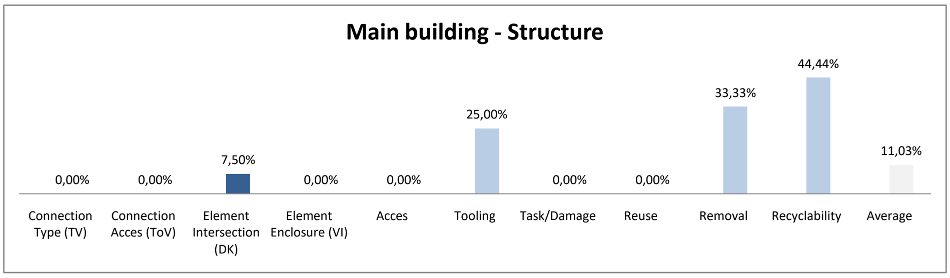
						Demountability Measuring tool 1 - Alba concepts							Demountability Measuring tool 2 - DFD - rating factors							
De Knip - Main building						Composition of element			Connection of element			Element Index	Ratings; 0 = Difficult; 9 = Easy							Scoring
ID 1	Element	ID 2	Underlaying element			TV	ToV	Lic elment	DK	VI	Lis Element	LI	Number of Parts	Acces	Tooling	Task	Reuse	Removal	Recyclability	Rating Score
29.01	Endplate Alum.	29.02	Endplate bracket	Sk	Rf	0,8	1	0,9	1	1	1	0,95	1	6	6	6	9	9	9	0,83
29.02	Endplate bracket	25.01	Concrete prefab facade element	Sk	Rf	0,8	0,8	0,8	0,4	0,2	0,3	0,55	1	6	6	9	9	6	9	0,83
29.03	Insulation 80mm	25.01	Concrete prefab facade element	Sk	Rf	0,6	0,4	0,5	0,4	0,1	0,25	0,375	1	3	6	3	3	6	0	0,39
29.04	Coated alum. Sheet piling	25.01	Concrete prefab facade element	Sk	Rf	0,8	1	0,9	1	0,8	0,9	0,9	1							0,00
29.05	2mm Alum. Cassette cladding	25.01	Concrete prefab facade element	Sk	Fa	0,8	0,8	0,8	1	0,8	0,9	0,85	1	3	6	6	9	9	9	0,78
25.01	Concrete prefab facade element	25.08	Concrete floor	St	Fa	0,1	0,1	0,1	0,4	0,1	0,25	0,175	1	0	3	0	0	3	4	0,19
25.02	Insulation 80mm	25.01	Concrete prefab facade element	Sk	Fa	0,6	0,4	0,5	0,1	0,1	0,1	0,3	1							0,00
25.03	Fixed dubbel glazed windowframe	25.01	Concrete prefab facade element	Sk	Fa	0,8	0,8	0,8	0,4	0,2	0,3	0,55	1	3	6	6	9	6	6	0,67
25.04	Natural stone windowsill 20mm	25.01	Concrete prefab facade element	Sk	Fa	0,1	1	0,55	1	1	1	0,775	1	9	6	6	6	6	4	0,69
25.05	2mm Alum. Cassette cladding	25.01	Concrete prefab facade element	Sk	Fa	0,8	0,8	0,8	1	0,8	0,9	0,85	1	3	6	6	9	9	9	0,78
25.06	Cable tray Plinth	25.07	Floor finishing	Sk	Fa	0,8	1	0,9	0,1	1	0,55	0,725	1	9	6	9	9	6	9	0,89
25.07	Floor finishing	25.08	Concrete floor	Sp	-	0,1	0,4	0,25	0,4	0,1	0,25	0,25	1	9	3	0	0	3	4	0,35
25.08	Concrete floor		Weighted floor strip	St	-	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	0	3	0	0	3	4	0,19
25.09	Ceiling system	25.08	Concrete floor	Sp	-	0,8	0,8	0,8	0,4	0,8	0,6	0,7	1	9	6	6	9	9	4	0,80
33.01	Prefab concrete column	33.01	Prefab concrete column	St	Fa	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	0	3	0	0	3	4	0,19
33.02	Interior wall	25.08	Concrete floor	Sp	-			0			0	0	1	9	6	9	9	6	6	0,83
33.03	Natural stone column cladding 30mm	33.01	Prefab concrete column	Sk	Fa	0,8	0,8	0,8	1	0,8	0,9	0,85	1	0	3	6	9	6	9	0,61
33.04	Insulation 80mm	33.01	Prefab concrete column	Sk	Fa	0,6	0,4	0,5	0,4	0,1	0,25	0,375	1	3	6	3	3	6	0	0,39
33.05	Rail window cleaning installation	33.01	Prefab concrete column	Sk	Fa			0			0	0	1	0	3	6	6	3	6	0,44
33.06	Sealant joint	33.01	Prefab concrete column	Sk	Fa	0,2	0,1	0,15	1	0,1	0,55	0,35	1	3	6	0	0	3	0	0,22
33.07	Water tight sealing	33.01	Prefab concrete column	Sk	Fa	0,1	0,1	0,1	1	0,1	0,55	0,325	1	0	3	0	0	3	2	0,15
33.08	P.V.C. 70mm tube 'bandraster' 1800	33.01	Prefab concrete column	Sk	Fa	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	0	0	0	0	0	2	0,04
30.01	1.5mm foil	25.01	Concrete prefab facade element	Sk	Pl	0,1	0,4	0,25	1	0,1	0,55	0,4	1	0	6	0	3	6	2	0,31
30.02	Natural stone 30mm	30.06	Foundation block	Sk	Pl	0,8	0,4	0,6	0,4	0,8	0,6	0,6	1	6	3	3	6	6	9	0,61
30.03	Copper mesh	30.02	Naturalstone 30mm	Sk	Pl			0			0	0	1	9	6	9	6	6	9	0,83
30.04	Foamglass 80mm	30.06	Foundation block	Sk	Pl	0,1	0,4	0,25	0,4	0,1	0,25	0,25	1	6	6	6	6	9	6	0,72
30.05	Floor finishing	25.08	Concrete floor	Sp	-	0,1	0,4	0,25	0,4	0,1	0,25	0,25	1	9	3	0	0	3	4	0,35
30.06	Foundation block		foundation pile	St	-	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	0	0	0	0	3	4	0,13

Apendix 3b.

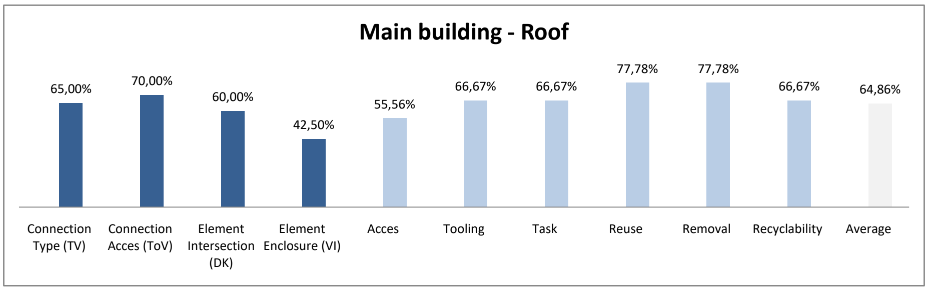
						Demountability Measuring tool 1 - Alba concepts							Demountability Measuring tool 2 - DFD - rating factors							
De Knip - Low rise						Composition of element			Connection of element			Element Index	Ratings; 0 = Difficult; 9 = Easy							Scoring
ID 1	Element	ID 2	Underlaying element			TV	ToV	Lic elment	DK	VI	Lis Element	LI	Number of Parts	Acces	Tooling	Task	Reuse	Removal	Recyclability	Rating Score
5.01	Natural stone Cover-up	5.04	Insulation 80mm	Sk	Rf	0,2	1	0,6	1	1	1	0,8	1	6	6	6	6	6	9	0,72
5.02	Natural stone cladding 30mm	5.03	Stainless steel wall-anchor	Sk	Rf	0,1	0,4	0,25	0,4	0,2	0,3	0,275	1	0	3	3	6	6	4	0,41
5.03	Stainless steel wall-anchor	5.10	Prefab facade element	Sk	Rf	1	0,4	0,7	0,4	0,1	0,25	0,475	1	3	0	3	6	3	4	0,35
5.04	Insulation 80mm	5.10	Prefab facade element	Sk	Rf	0,6	0,4	0,5	0,1	0,1	0,1	0,3	1	3	6	3	3	6	0	0,39
5.05	Roof floor tiles	5.06	Water repellent layer	Sk	Rf	1	1	1	1	1	1	1	1	9	6	9	9	9	6	0,89
5.06	Water repellent layer	5.09	Insulation Roof 80mm	Sk	Rf	0,1	0,8	0,45	0,4	0,8	0,6	0,525	1	6	3	3	0	6	2	0,37
5.07		5.08	Fall-Layer	Sk	Rf	0,6	0,8	0,7	0,4	0,8	0,6	0,65	1							0,00
5.08	Fall-Layer	5.09	Insitu Concrete floor 230mm	Sk	Rf	0,1	0,1	0,1	1	0,1	0,55	0,325	1	3	0	0	3	3	2	0,20
5.09	Insitu Concrete floor 230mm	5.10	Prefab facade element	Sk	Rf	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	3	0	0	0	0	0	0,06
5.10	Prefab facade element	5.09	Insitu Concrete floor 230mm	St	Rf	0,1	0,1	0,1	0,4	0,1	0,25	0,175	1	3	0	0	0	0	0	0,06
3.01	Prefab facade element	3.02	Insitu Concrete floor 230mm	St	Fa	0,1	0,1	0,1	0,4	0,1	0,25	0,175	1	3	0	0	0	0	0	0,06
3.02	Insitu Concrete floor 230mm	3.01	Prefab facade element	St	-	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	3	0	0	0	0	0	0,06
3.03	Insulation Inside 80mm	3.02	Insitu Concrete floor 230mm	Sk	Fa	0,6	0,4	0,5	0,1	0,1	0,1	0,3	1	3	6	3	3	6	0	0,39
3.04	Closed raster ceiling (outside)	3.02 & 3.01	Concrete Floor & Facade	Sk	Fa	0,8	0,8	0,8	0,4	0,8	0,6	0,7	1	6	6	6	3	6	4	0,57
3.05	Natural stone cladding 30mm (column)	3.06	Prefab concrete column 450x450	Sk	Fa	0,1	0,4	0,25	0,4	0,2	0,3	0,275	1	3	3	3	6	6	4	0,46
3.06	Prefab concrete column 450x450		Foundation	St	Fa	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	3	0	0	0	0	0	0,06
1.01	Floor finishing	1.02	Concrete floor	Sp	-	0,1	0,4	0,25	0,4	0,1	0,25	0,25	1	9	3	0	0	3	4	0,35
1.02	Concrete floor		Foundation block	St	-	0,1	0,1	0,1	0,1	0,1	0,1	0,1	1	0	3	0	0	3	4	0,19
1.03	Natural stone windowsill 20mm	1.04	Concrete prefab facade element	Sk	Pl	0,1	1	0,55	1	1	1	0,775	1	9	6	6	6	6	4	0,69
1.04	Concrete prefab facade element	1.02	Concrete floor	St	Pl	0,1	0,1	0,1	0,4	0,1	0,25	0,175	1	0	3	0	0	3	4	0,19
1.05	Sandwich panel	1.06	Alum. Curtain wall	Sk	Pl	0,8	1	0,9	1	0,1	0,55	0,725	1	9	6	9	6	9	2	0,76
1.06	Alum. Curtain wall	1.04	Concrete prefab facade element	Sk	Pl	0,8	0,8	0,8	0,4	0,2	0,3	0,55	1	3	6	6	9	6	6	0,67
1.07	Foamglass 80mm		Foundation block	Sk	Pl	0,1	0,4	0,25	0,4	0,1	0,25	0,25	1	6	6	6	6	9	6	0,72
1.08	Concrete pavement tiles		Sand	Sp	Pl	1	1	1	1	1	1	1	1	9	6	9	9	9	6	0,89

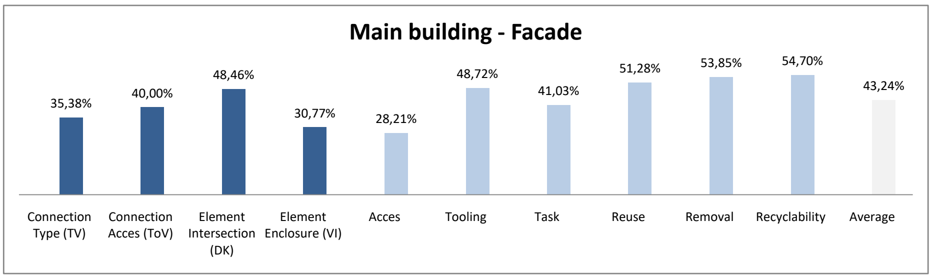
Apendix 4a.

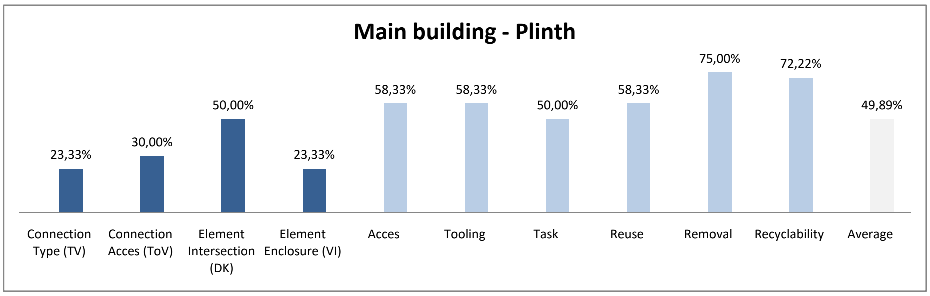




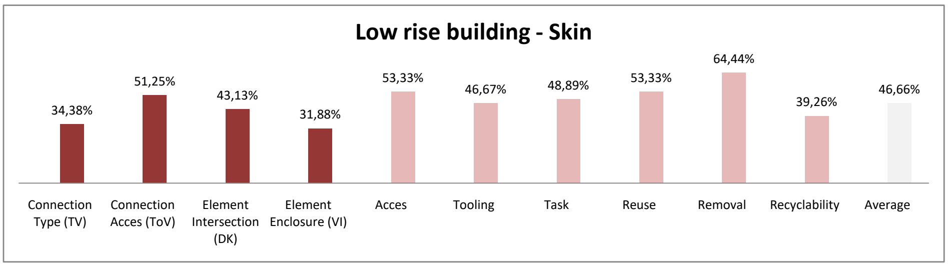
Apendix 4b.

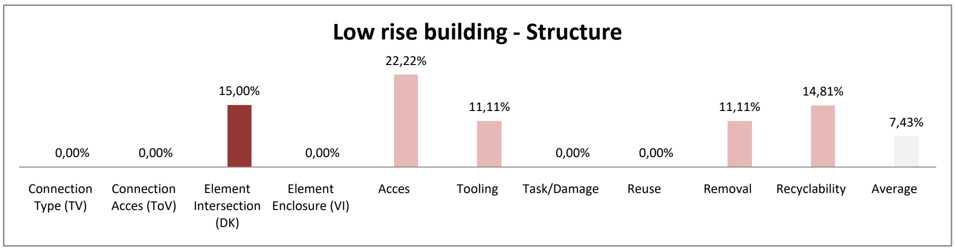




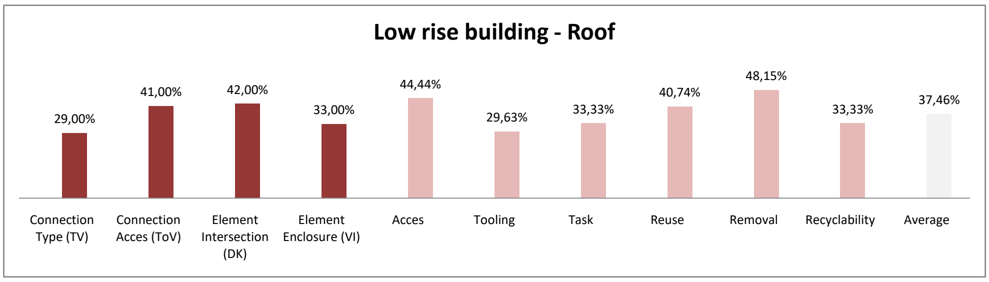


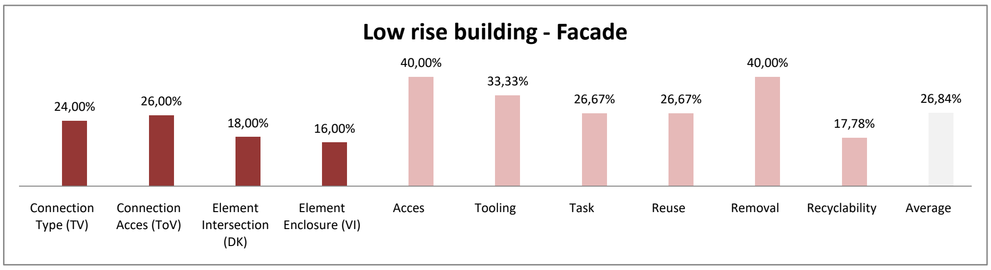
Apendix 4c.

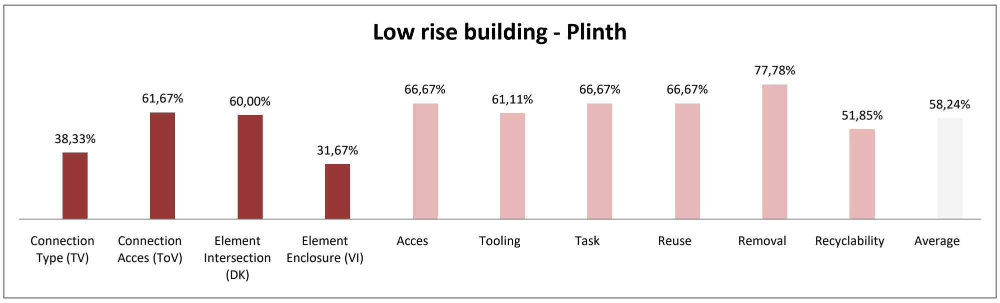




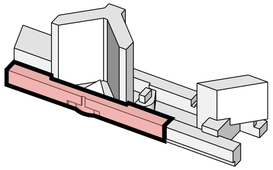
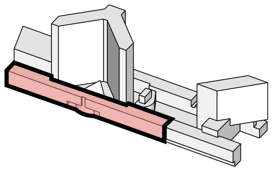
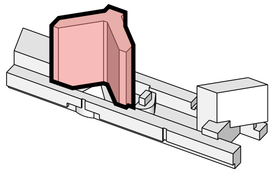
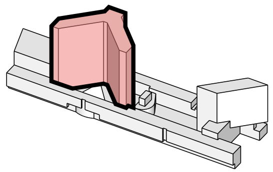
Apendix 4d.



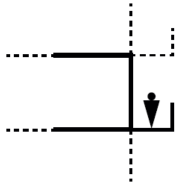
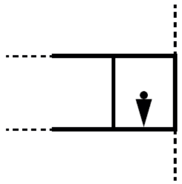
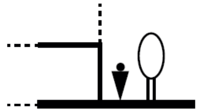
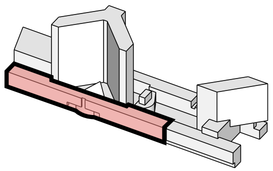
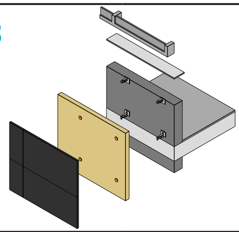
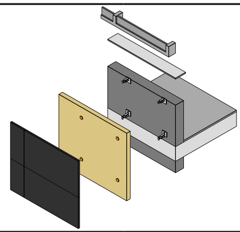
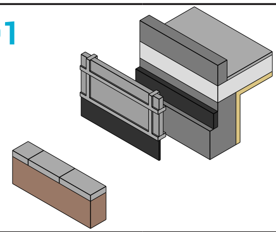
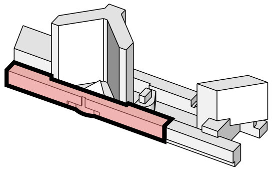
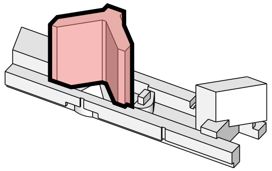
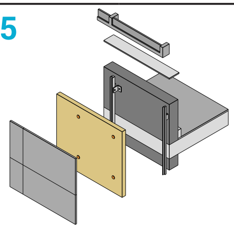
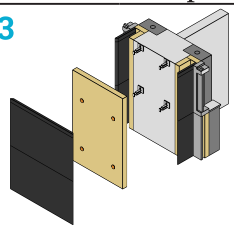
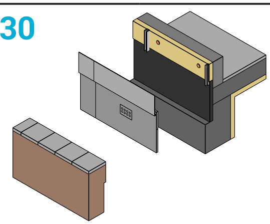
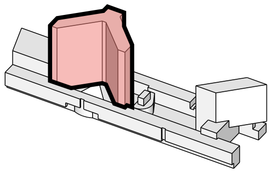




Apendix 5a.

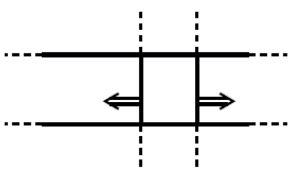
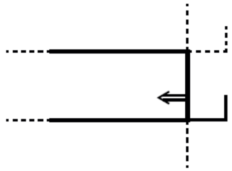
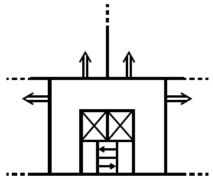
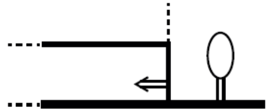
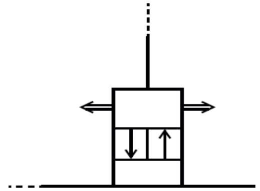
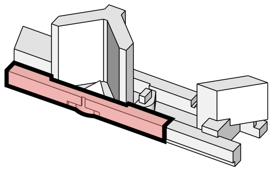
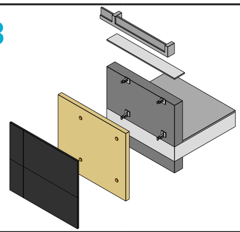
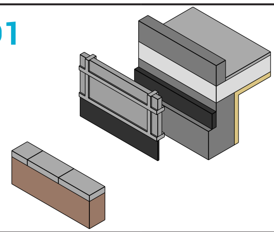
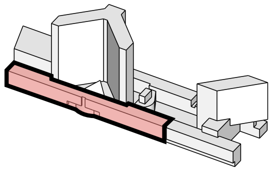
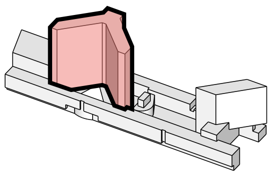
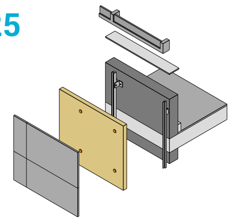
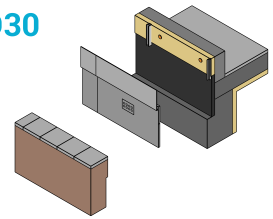
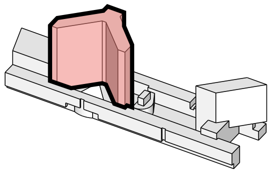
	Daylight	Thermal Insulation	Acoustic Insulation
TECHNICAL PROPERTIES	Minimum	Minimum	Minimum
De Knip 1994, Low Rise	-	[Building code 4 art. 70 - 1992]	[Building code 2 art. 22 - 1992]
	-	Roof: Rc 2,5 m2K/W Facade: Rc 2,5 m2K/W Floor Rc 2,5 m2K/W	Acoustic insulation min. 20dB; resulting noise level max. 35dB
De Knip 2021+, Low Rise	[Building code 3.11 - 2021]	[Building code 5.1 art. 5.3 - 2021]	[Building code 3.3 - 2021]
	Living zone (verblijfsgebied) 10% of floor area m2 & daylight surface > 0.5m2	Roof: Rc 6,3 m2K/W Facade: Rc 4,7 m2K/W Floor Rc 3,7 m2K/W	Acoustic insulation min. 20dB; resulting noise level max. 33dB
De Knip 1994, High Rise		[Building code 4 art. 70 - 1992]	[Building code 2 art. 22 - 1992]
	-	Roof: Rc 2,5 m2K/W Facade: Rc 2,5 m2K/W Floor Rc 2,5 m2K/W	Acoustic insulation min. 20dB; resulting noise level max. 35dB
De Knip 2021+, High Rise	[Building code 3.11 - 2021]	[Building code 5.1 art. 5.3 - 2021]	[Building code 3.3 - 2021]
	Living zone (verblijfsgebied) 10% of floor area m2 & daylight surface > 0.5m2	Roof: Rc 6,3 m2K/W Facade: Rc 4,7 m2K/W Floor Rc 3,7 m2K/W	Acoustic insulation min. 20dB; resulting noise level max. 33dB

Apendix 5b.

	External	Internal	Garden
OUTDOOR SPACE			
Description	Outdoor space along the façade.	Outdoor space within the outline of the building.	Outdoor space directly adjacent tot the dwelling.
De Knip 1994, Low Rise 	D3 	D3 	D1 
De Knip 2021+, Low Rise 	Skin: ••• Structure: • Structure prevents access/door placement.	Skin: ••• Structure: •• Existing prefab concrete elements can be used as internal outdoor space.	Skin: •••••• Structure: • Preface facade element main load bearing structure.
De Knip 1994, High Rise 	D25 	D33 	D30 
De Knip 2021+, High Rise 	Skin: •••• Structure: •• Difficulty to demount the preface facade elements; can be adjusted.	Skin: •••• Structure: •• Columns in facade are part of the main load bearing structure.	Skin: ••••• Structure: •• Difficulty to demount the preface facade elements; can be adjusted.

Legenda •••••••••• 100-90% Demountability score
• 10-0% Demountability score

Apendix 5c.

	Corridor	Balcony	Central core	Street	Portico
ACCESS ROUTING					
Description	Access via a common horizontal traffic route within the building, not located on the facade.	Access via a common horizontal circulation space along the façades.	Access via a communal elevator (and [escape] stairwell).	The entrance is directly accessible from ground level.	Accessed via a common stairwell.
De Knip 1994, Low Rise 	Floor, Clomn, Interior wall	D3 	Main cores	D1 	Floor, Facade
De Knip 2021+, Low Rise 	Skin: n/a Structure: ••••••••• Existing corridor. Free column structure.	Skin: ••• Structure: • Structure prevents access/door placement.	Skin: n/a Structure: • Solid concrete cores. However comply to a residential building.	Skin: •••••• Structure: • Preface facade element main load bearing structure.	Skin: ••• Structure: • Cavity in floors are needed.
De Knip 1994, High Rise 	Floor, Clomn, Interior wall	D25 	Main central cores	D30 	Floor, Facade
De Knip 2021+, High Rise 	Skin: n/a Structure: ••••••••• Column structure allows for corridor.	Skin: •••• Structure: •• Difficulty to demount the preface facade elements; can be adjusted.	Skin: n/a Structure: • Solid concrete central cores. However comply to a residential building	Skin: ••••• Structure: •• Difficulty to demount the prefab facade elements; can be adjusted.	Skin: ••• Structure: • Cavity in floors are needed or exterior options possible.

Legenda •••••••••• 100-90% Demountability score
• 10-0% Demountability score

Apendix 6a.

LIc_n = losmaakbaarheidsindex van de connectie van element *n*:

- TV_n = type verbinding van element *n*;
- ToV_n = toegankelijkheid verbinding van element *n*.

$$LIc_n = \frac{TV_n + ToV_n}{2}$$

LIs_n = losmaakbaarheidsindex van de samenstelling van element n:

- DK_n = doorkruisingen van element *n*;
- VI_n = vorminsluiting van element *n*.

$$LIs_n = \frac{DK_n + VI_n}{2}$$

LI_n = losmaakbaarheidsindex van element *n*.

$$LIs_n = \frac{LIc_n + LIs_n}{2}$$

Type verbinding		Score
Droge verbinding	Droge verbinding	1,00
	Klikverbinding	1,00
	Klittenbandverbinding	1,00
	Magnetische verbinding	1,00
Verbinding met toegevoegde elementen	Bout- en moerverbinding	0,80
	Veerverbinding	0,80
	Hoekverbindingen	0,80
	Schroefverbinding	0,80
	Verbindingen met toegevoegde verbindingselementen	0,80
Directe integrale verbinding	Pin-verbindingen	0,60
	Spijkerverbinding	0,60
Zachte chemische verbinding	Kitverbinding	0,20
	Schuimverbinding (PUR)	0,20
Harde chemische verbinding	Lijmverbinding	0,10
	Aanstortverbinding	0,10
	Lasverbinding	0,10
	Cementgebonden verbinding	0,10
	Chemische ankers	0,10
	Harde chemische verbinding	0,10
Toegankelijkheid verbinding		**Score**
Vrij toegankelijk		1,00
Toegankelijkheid met extra handelingen die geen schade veroorzaken		0,80
Toegankelijkheid met extra handelingen met herstelbare schade		0,40
Niet toegankelijk – onherstelbare schade aan objecten		0,10
Doorkruisingen		**Score**
Modulaire zonering van objecten		1,00
Doorkruisingen van één of meerdere objecten		0,40
Volledige integratie van objecten		0,10
Vorminsluiting		**Score**
Open, geen insluitingen		1,00
Overlappingen aan één zijde		0,80
Gesloten aan één kant		0,20
Gesloten aan meerdere kanten		0,10

Apendix 6b-I.

5. Design for disassembly

The DFD part of the analysis is based on the AR^3T^3 method (Shetty and Schumacher), which stands for Access, Removal, Reuse, Recycle, Tool, Task and Time. Each of these areas will be explained in detail below.

5.1 Access rating

Access is defined as the ease with which a part can be approached and removed. Rating is given in the range of 0-9 with 0 being hard to access and 9 easy (Table IV).

Table IV Access rating

Access description	Rating	
Area is easy to work in, ample space for hands/tools	9	Easy
Area has restricted access, but part can be removed without damage	6	
Area/vision restricted, special care required to remove without damage	3	
Area very difficult to access, special care/tooling/techniques required to remove part without damaging it	0	Difficult

5.2 Tool rating

Ratings are based on whether the task is accomplished by hand or by common hand tools or with the help of special tools. The description of the ratings is given in Table V.

Table V Tool rating

Tooling description	Rating	
Tool is not required; task is accomplished by hand	9	Easy
Common hand tool required	6	
Special tooling/equipment required, without time delay	3	
Special tooling/equipment required, with time delay	0	Difficult

5.3 Task/Damage rating

Ratings are based on the ease with which the task is accomplished or care to be taken to avoid any damage in the process of removal. The damage described here refers to the damage of the part being removed (Table VI).

Table VI Task/Damage rating

Task/damage description	Rating	
Task easily accomplished with little concern for part damage	9	Easy
Destructive assembly is the only known method to remove the part; The part cannot be reused for the same purpose after removal	6	
Task is easily accomplished, however this part is considered fragile and can be easily damaged without proper care	3	
Typically the part is damaged during the task and great care must be taken during its removal to reduce additional damage	0	Difficult

5.4 Re-use rating

Ratings are based on the level of re-use of the part being removed. Reconditioning is necessary if the part suffers damage in the process of removal (Table VII).

Table VII Re-use rating

Re-use description	Rating	
Reuse with no reconditioning required (part in good condition or no degradation during use	9	Easy
Reuse after reconditioning	6	
Reuse after special separation techniques applied to assemblies followed by reconditioning	3	
Cannot be re-used, too time-consuming/expensive	0	Difficult

Apendix 6b-II.

5.5 Removal rating

Removal is defined as the process of removing the part from the assembly without damaging it or the adjacent parts surrounding the part in the assembly (Table VIII).

Table VIII Removal rating

Removal description (Adjacent part damage/re-use)	Rating	
The part is removed with NO damage to adjacent parts	9	Easy
The part is removed with minor damage (or potential for) to the adjacent part(s), but they can be reconditioned easily to re-use	6	
Significant/difficult reconditioning required to the adjacent part(s) due to the removal of current part, making potential re-use less likely	3	
Adjacent part sustains major damage during part removal and cannot be reconditioned for re-use. Throw away or recycle	0	Difficult

5.6 Recyclability (material) rating

Recyclability can be defined as the ease with which a material can be recycled safely and economically. Ratings have been given based on the recyclability of the materials present in the assembly (Table IX).

Table IX Recyclability (material) rating

Recyclability description (material rating)	Rating	
Part is made of one non-hazardous material, easily recyclable	9	Easy
Part is made of dissimilar non-hazardous materials that are easily separable and recyclable (or no need to separate materials)	6	
Part is made of dissimilar non-hazardous, recyclable materials, but separation is difficult	4	
Part is made of one or more non-hazardous materials but cannot be recycled, even if separated	2	
Part is made of hazardous material(s)	0	Difficult