The Circular Procurement Tool

Procurement method to stimulate circular facade systems in mid-rise residential buildings in the Netherlands

Ir. **Juliëtte Mohamed**

TU Delft

Gemeente Amsterdam

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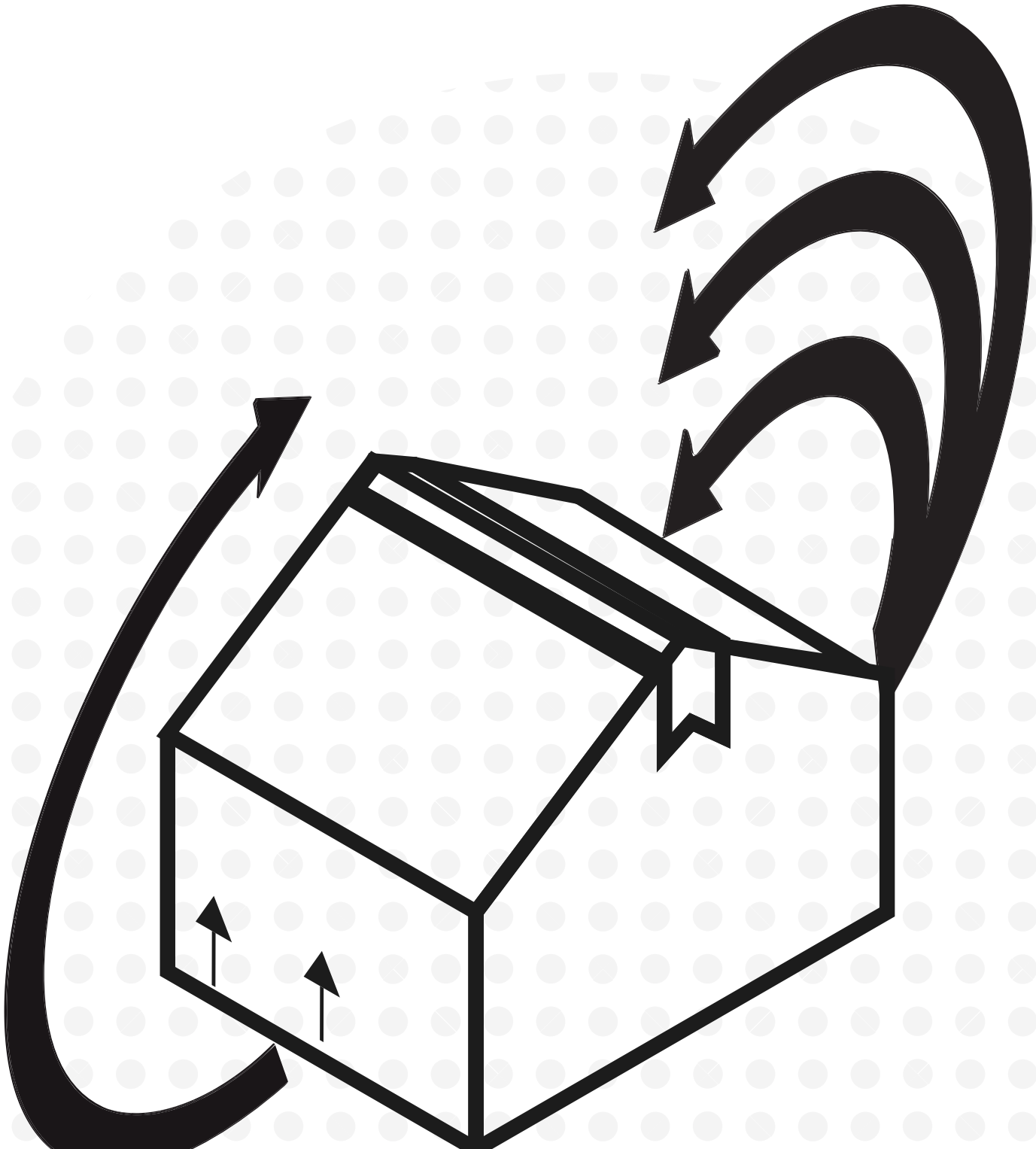

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MSc thesis Delft University of Technology

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Master of Science (MSc) thesis
Procurement method to stimulate circular facade systems in mid-rise residential buildings in the Netherlands

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Abstract

More attention has been paid to sustainability in buildings in the last decades, leading to increased operational energy performance. The development of stricter legislation on building energy performance has stimulated façade design to include technical criteria that had not been included before but, paradoxically, has led to an increase in the use of materials and reduction of the ability to recover products of material that still contain high embodied energy after its first service life. Combined with the 'take-make-dispose economic model that is still prevailing in the building industry, it results in a high amount of material waste during construction and demolition of buildings, making the building sector the most prominent energy and natural resources user (Eurostat European Commission, 2019). To counteract this waste production, new models have been created. One of them is the circular economy that tries to restore the pressure on earth's life-supporting systems. The Netherlands' ambition is to have a fully circular economy by 2050, while from 2030, tenders on all governmental levels should be circular.

Procurement has a significant influence on the initiation of circularity in the project. The more circular projects are asked on the market, the more advisers, contractors and suppliers have to implement them into their design proposal. However, most project developers lack the in-house knowledge of clarifying their circular aim in tendering, which results that the parties involved will only steer on reduction of the energy consumption rather than going fully circular when sustainability is included as an award criterion.

Therefore, the question of this research is: "In what way can a procurement method stimulate the implementation of circular façade systems in mid-rise residential buildings in the Netherlands." In answer to this question, the thesis proposes the circular procurement tool, which all key- parties can use during the procurement.

The tool can help public authorities such as the municipality set circular binding conditions for the project in exchange to hand over land to the project developer. In this way, the municipality will be able to initiate and demand the circular ambition for the project. The tool can help the project developer make the practical implications of these circular ambitions explicit and help the parties involved early in the process with the tender's selection procedure. Furthermore, the tool can categorise and assess the individual benefits of the circular measures in facade systems and products. By utilising this tool, monitoring during the process becomes possible and gives the opportunity to evaluate the realisation of the set requirements. The tool is based on the circular economy principle and offers a framework to categorise the impact on the environment into three main themes; Reducing the input of raw materials, Streamlining the material output, and Lowering the pressure on the natural capital. These main themes can be split up into categories and subcategories to further specify the circular ambition. Firstly, the municipality should decide which of the three main categories should be focused on by determining weighting factors based on the levels of the already existing 'Ambitieweb'. Secondly, the project developer can further divide weighting factors over the various (sub)categories. These weighting factors will be translated into points that will form the circular criteria of the tender. The parties and façade systems can be assessed in these subcategories and achieve points accordingly. The results will be shown in a radar chart to provide an overview of all tenders, making it possible to compare and evaluate them on the initial ambition.

To validate the tool, the method has been tested on the product and building system level. The results clarify how the products and systems are circular and in what circular aspects improvement is possible. The tool is evaluated through a deep renovation project at location Reigersbos, Amsterdam, where circular facades will be applied on mid-rise residential buildings that have been built in 1984. The current process of setting circular ambitions for the project has been compared with the same process and the tool's help. In this case study project, a selection procedure has taken place to unify different parties that were willing to work together. However, such a tender process is complex and justifying the circular procurement seems complicated at the performance level. Through its systematic framework, the tool can offer a structured process that makes evaluation possible and can make the process less time-consuming. Interviews with field experts have been conducted for feedback on the tool in terms of functionality. It is said that the tool supports the design process and can lead to responsible and knowledgeable decisions rather than replacing the design process to generate generic solutions. For the (facade) contractor, the tool offers an easy-view to determine if their services would fit the project requirements and to see if changes in the system's design or supply chain are needed. Furthermore, from the supplier's perspective, the tool provides the opportunity to improve their products to the market's demands. Nowadays, it is not always known which sustainable innovation should be prioritised, which leads to a high amount of inefficient product development.

Keywords: Procurement , Tender, Circular economy, Facade, Circular Procurement method, Procurement Tool

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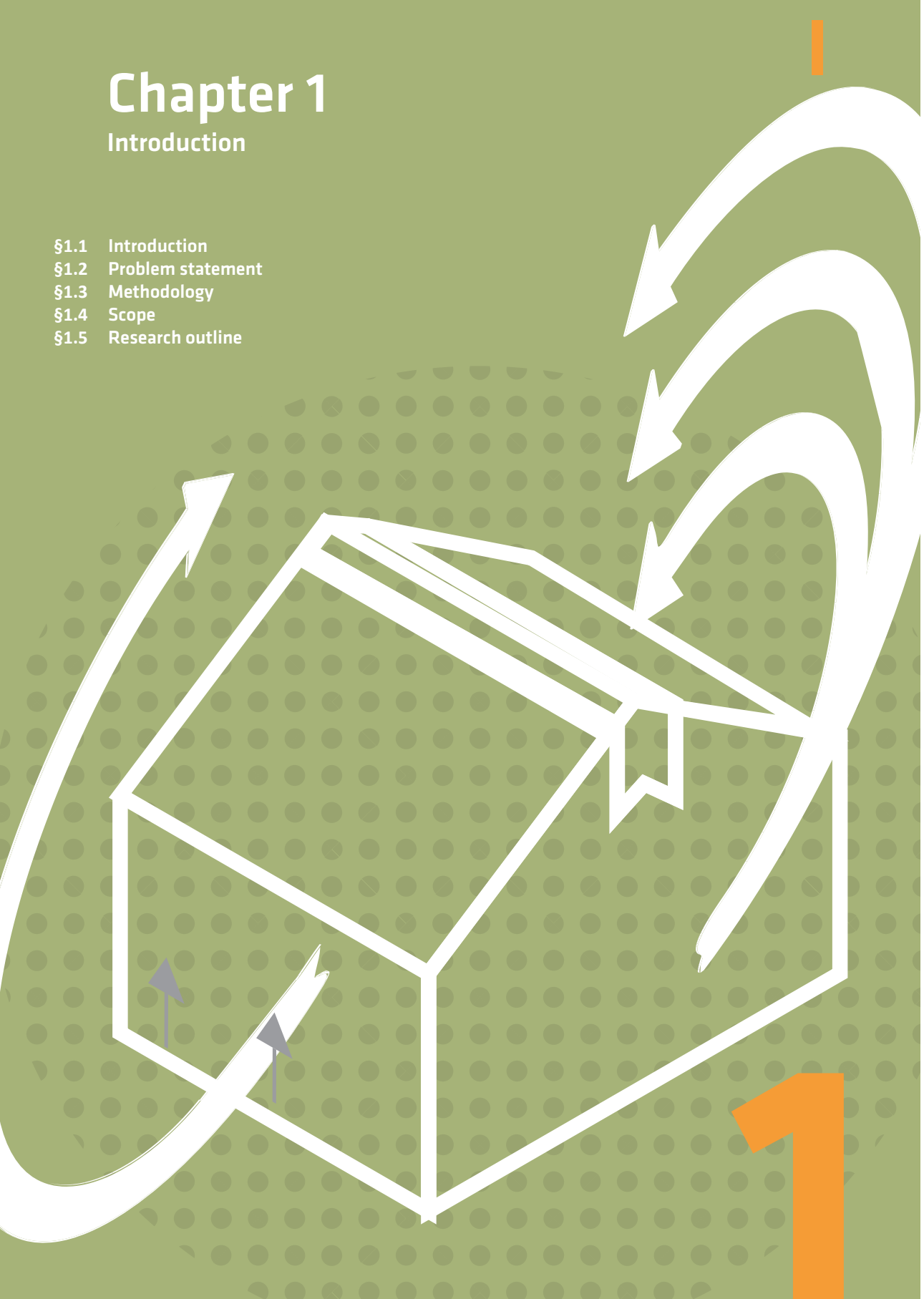
Chapter 1
Introduction

§1.1 Introduction
§1.2 Problem statement
§1.3 Methodology
§1.4 Scope
§1.5 Research outline



1.1 Introduction

In the last decade more attention has been paid to increase the operational energy performance of buildings. Development in stricter legislation on building energy performance has stimulated façade design to also include technical criteria that hasn't been included before. This is partly the reason of an increase in the use of materials, processing methods and construction techniques, which paradoxically may reduce the ability to recover material that still contains high embodied energy after its first use. While, the ability to recover the materials is not usually considered (Hartwell & Overend, 2020). This combined with the take-make-dispose model that is still prevailing in the building industry, results in a high amount of material waste during construction and demolition of buildings. Especially residential buildings often need to be demolished and rebuilt due to obsolescence for different reasons.

The current situation in the Netherlands is a tight housing market. This is caused by factors such as population growth, migration to urban regions, an increase in one-person households, low interest rates and increased incomes while the construction of housing has lagged far behind because of the last economic crisis. The demand for new housings grows and in order to handle the even more rapidly rising house prices, long waiting lists in social rent, and a large shortage of affordable mid-rental homes. In the Nationale woonagenda (2018) the goal is already set to realize 75000 new homes per year in the period of 2018-2021 where a rapid and constant method to maintain good quality housing is desired but not evolved yet. Also, these numbers, will not be reached according to the already known permit numbers that have been retrieved (Koning & Kragt, 2020).

At the same time, the city of Amsterdam is planning on refurbishment of 12 800 houses in the district Amsterdam Zuidoost in order to become more energy neutral. The project location 'Reigersbos' consists of 288 houses divided over 10 blocks mid-rise (height of 13-70 m) apartment blocks that need a new facade. The renovation ambition is to use circular, modular, prefab systems with high insulated values. As more than 32 % of the total existing apartments in this area need to be renovated, this project can be the start to implement the strategies of the circular economy in housing projects on a large scale (Gemeente Amsterdam, 2019).

1.2 Problem statement

The Netherlands is one of the five European countries with the most construction and demolition waste a year (JRC European Commission, 2011). The Netherlands aims for the policy to develop a circular economy by 2050. The building sector, the biggest energy, and natural resources user, is responsible for 36.4 % of the total waste generation. for more than 35% of the global final energy use and for nearly 40% of energy-related CO2 emissions (Eurostat European Commission, 2017).

The research of W/E adviseurs (2017) shows that the building envelope is accountable for nearly 15 to 21% of the total environmental impact (figure 1.1.) The installations are accountable for the largest environmental impact which are necessary because of the high energy performance requirements that are still increasing. When more energy strategies shift towards the building envelope by for instance the use of solar panels, the share of the building envelope increases as well. Therefore it is and becomes increasingly important to focus next to the operational energy performance of buildings also on the material efficiency (Vosmaer, 2020).

The ambition of the Netherlands is to have a fully circular economy by 2050, while from 2030 tenders on all governmental levels, national, provincial, and municipal, should be circular (Transitieteam, 2018). However, there is still a lot of uncertainty on the definition of a circular economy and a way to achieve circular products within the (building) industry.
A problem that occurs with the transition towards a circular economy, is the changing role of the involved parties and their responsibility. What objectives and requirements can exactly be asked for and by whom, to call it a circular project? Therefore, this thesis aims to answer the following research question:

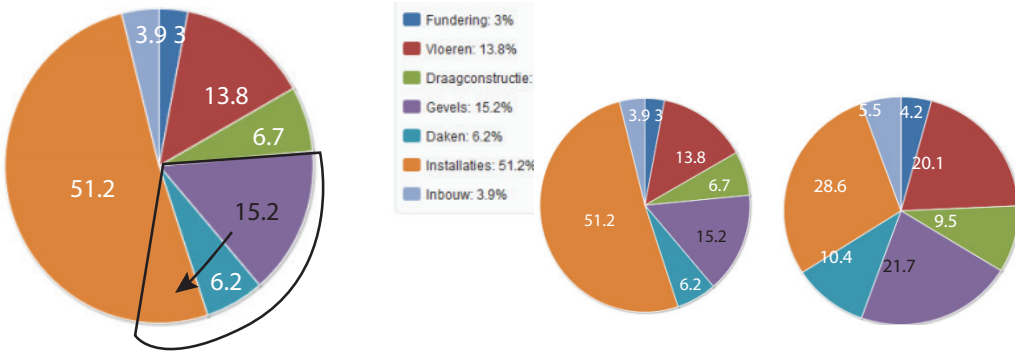


Figure 1.1: The increase of share of the building envelope of a residential appartment in between other appartments that goes from gas(middle) to all-electric(left). based on: (W/E adviseurs, 2019)

1.3 Methodology

"In what way can a procurement method stimulate the implementation of circular façade systems in mid-rise residential buildings in the Netherlands"

The research question is divided into three sub-questions:

- **How is circularity defined in the built environment?**
- **What are the requirements of the façade to prevent obsolescence of a building?**
- **What are the potential bottlenecks of the circular economy in the residential building sector to overcome?**

§1.3.1 **How is circularity defined in the built environment?**
To answer this question, literature research conducted to get to know the definitions of a circular economy in the built environment in both international research papers as practical approaches from the Dutch government are conducted.

§1.3.2 **What are the requirements of the façade to prevent obsolescence of a building?**
After defining the different possible circularity strategies, it is important to know how the building is a total and how the materials of the façade are affected by its environment and circumstances to gain insight into the possible life span and what measures can be taken to elongate it. For this, different research papers have been read, and a summary of the key principle is made.

§1.3.3 **3) What are the potential bottlenecks of the circular economy in the residential building sector to overcome?**
At the moment we are in a transition from a linear to a circular economy, therefore there are already conclusions on several pioneering circular projects. A literature research is done on a broad level taking into account the possible problems of a circular economy in the building industry in the Netherlands.
As different stakeholders can face other obstacles, it is thus important to understand what the bottlenecks are for these parties and how their role could change during and after the transition.

These answers will lead to formulation of the design brief for the answer of the research question.

§1.3.4 **"In what way can a procurement method stimulate the implementation of circular façade systems in mid-rise residential buildings in the Netherlands"**

The thesis's goal is to develop a procurement method that can help the involved parties steer towards a circular economy through procurement. By addressing the problems and incentives found in the literature, a design brief for this procurement can be drafted, and a circular procurement tool can be developed. The tool should make it able to assess parties and facade systems to enhance the project's circularity.

§1.3.5 **Scope**

The tool will be based on mid-rise residential buildings (13-70 m) in the Netherlands. The share of this typology of houses in the existing building stock is 29% (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties,2013), while 20-30 % of the set goal to build 75000 new houses in the period from 2018-2021 will involve mid-rise residential buildings. Focussing on every aspect of a building would not fit in the duration of this research project. The research focuses, therefore, on façade elements only. However, the proposed methodology can later be expanded to other main aspects of a building, namely the construction and building services

§1.3.6 **Research outline**

The thesis has been written in the structure 'From broad to zoomed in' and consists of four parts which can be seen in figure 1.2. Part I consists only of the first chapter, chapter 1, where the research definition is formulated. The research definition introduction to the topic, a description of its objective, and the scope of this research.

Part II is the literature research that introduces the reader to the required background knowledge. The literature research forms the input for the concept of this thesis. Part II is divided into three topics. Each of these three topics covers one chapter. Chapter 2 describes the design principles of a circular design. Chapter 3 provides information about the requirements of buildings that complement or amplify the circular design principles. Chapter 4 introduces the many parties and stakeholders involved in residential building projects. It is up to these parties to stimulate the transition towards a circular economy. The foreseen bottlenecks of this transition will also be described in chapter 4 and form the main input for developing the concept of this thesis.

Part III shows the concept for this research. Chapter 5 formulates the design brief and introduces the idea that is generated by the literature research. Chapter 6 Is the validation of the circular procurement tool that has been developed. For this validation, a test has been conducted on building products. Furthermore, market analysis with experts from the field has been carried out. A case study project is used to point out how the circular procurement tool can help the involved parties during a procurement and design process.

Part IV Concludes this thesis in chapter 7. This part includes the most important findings of this research, a discussion, and a recommendation.

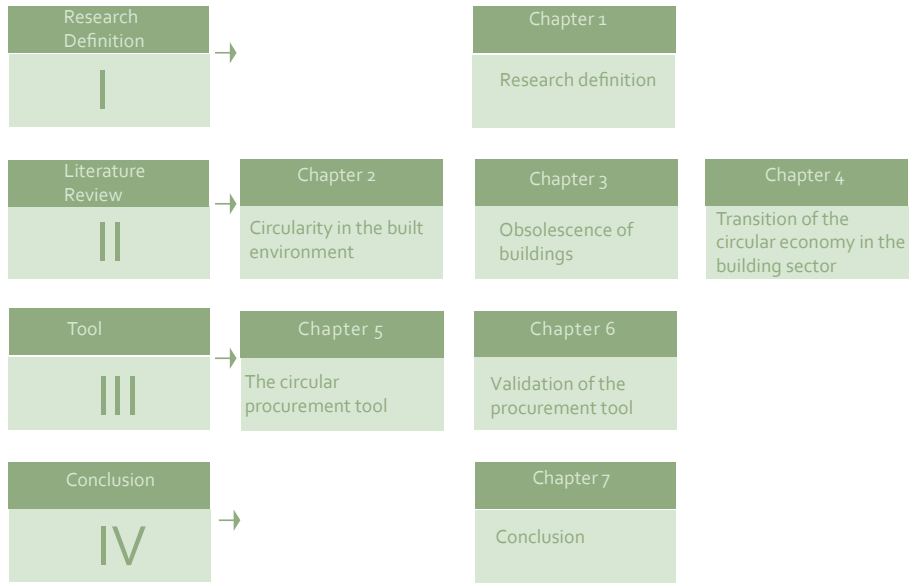


Figure 1.2: Research outline .(Own figure)

Chapter 2

Circularity in the built environment

§2.1 Circularity defined
§2.2 Outline of the circular economy
§2.3 Circular strategies
§2.4 Distinction in building layers
§2.5 Existing guidelines for demount ability and accessibility
§2.6 Summary

In this chapter the circularity principles that are applicable to the building industry will be investigated. The chapter will start with the outline of the circular economy. Paragraph 2.2 will explain what the principle of the circular economy is and will describe the most used definitions. Paragraph 2.3 introduces several strategies of the circular economy and how they have been implemented into building projects. Paragraph 2.4 will explain the distinction in building layers to show the complexity of replacing those layers during its lifetime. Paragraph 2.5 sets out guidelines to implement demountability and accessability.

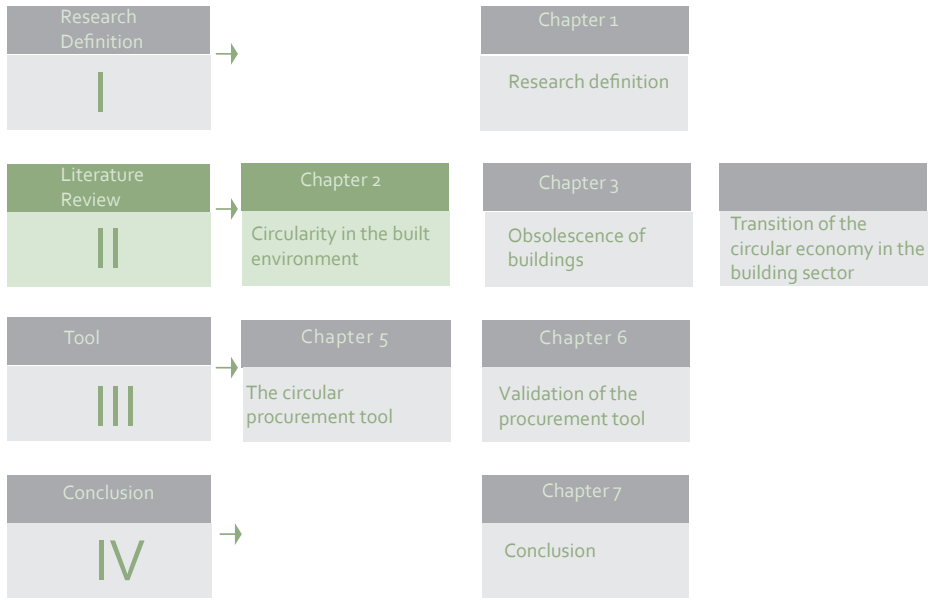


Figure 2.1: Place of chapter 2 in the thesis. Source: Own figure.

2.1 Circularity defined

Sustainability deals with many aspects and this issue is high on the agenda of companies and public authorities. A lot of attention has been given to energy production and reduction of the usage of fossil fuels. The development of stricter legislation on building energy performance has stimulated façade design to include technical criteria that had not been included before and has led to an increase in the use of materials. Paradoxically, this reduces the ability to recover products and material that still contain high embodied energy after its first service life (Hartwell & Overend, 2020). The decrease of energy usage and fossil fuels is thus not the only factor for a sustainable project. Mining raw materials to create products also adds to the global emissions of CO^2. Furthermore, raw material can only be mined once and will not grow back. Therefore, depletion of materials has to be prevented. In the European Union a total of 2509.9 million tons of waste was produced in 2014. From this total sum almost 47% goes to landfill, 10% to backfill and about 37% is recycled. The remains are burned (Eurostat, 2014). An important part to solve the sustainability issue is, according to Wijngaard (n.d.) of TNO , a circular economy.

According to Yuang, Bi, & Yuichi (2006) the precise definition of the circular economy is not yet commonly accepted, but the core meaning is clear: a (closed) flow of materials where raw materials and energy go through multiple phases.

According to the lexicon of Platform CB'23 (2019) the CE is defined as follows: "*The circular economy is an economic system in which we maximize the value of raw material flows, without hindering the functioning of the biosphere and the integrity of society".* This means, among other things, that reusability of products and materials is created, that future reuse is guaranteed and that value destruction is thus prevented.

The Lente-akkoord ZEN (2017) describes circularity, in terms of the building industry, as follows and puts the focus more onto the practical and technical aspect: "*To build without waste, minimum usage of resources while at least taking into account BENG* and maintain respect for the environment*".

A more detailed description of a circular economy is according to the Ellen Macarthur foundation (2016): "*Circular economy is a global economic model that aims to decouple economic growth and development from the consumption of finite resources. It is restorative by design, and aims to keep products, components and materials at their highest utility and value, at all times.*" The definition of the Ellen MacArthur foundation indicates that not only material flows are important, but also the natural capital (other than materials) needs to be protected. Furthermore, it is recognised that economic principles such as value creation and prevention of ownership is important.

* BENG: Bijna Energieneutrale gebouwen/ Nearly Energy Neutral Buildings .

As can be seen, there are many different definitions and interpretations on the concept of a circular economy in every sector. The principle of the circular economy tries to restore the pressure on earth's life-supporting systems. One of the main themes of the circular economy is to close the material cycle. This can be achieved by stopping the need to mine raw materials and by streamlining the mined materials to prevent them from turning into waste. The other factor is to reduce the impact on the natural capital. To turn materials into products, resources such as fresh water and energy are spent and all sorts of (undesirable) by-products may get released in the environment.

- Reduce the input of raw materials
  By controlling the minable,finite stock and balance the renewable material flows to preserve and enhance materials that belong to the natural capital(figure 2.2).
- Prevention of waste materials
  This implies material recovery of the technical material and cascading of renewable material. The biological nutrients can return to the soil and enable new plants to grow. It can be collected and manufactured into new organic materials, preventing waste by streamlining the material output.
- Pressure release on the natural capital (other than materials)
  Protect and regenerate the natural capital such as the geology, soil, air and water.

The idea of a sustainable economy is not entirely new, since the 1980's many new sustainable system models have been developed on how sources of nature can be restored. The circularity principle is based on these (Leising, 2017). Looking at the strategies (table 2.1) the most common terms are: waste reduction, waste elimination, minimalise material consumption, reduce energy consumption, and preventing ownership of products and components.

The thesis is based on the principle of the circular economy but will also use the work of the Ellen Macarthur foundation (2015) as it is the most elaborated, used and recognised theory at this moment which willl also make it tranparent for follow-up projects.

Figure 2.2: The three main themes of a circular economy

Fields of study	Key principles
Performance economy (StahelReday-Mulvay, 1981)	**Product-service systems:**Paying per use to prevent ownership and disposal of used products/ parts. **Performance-based:** Paying for the performance to reduce resource use and waste production.
The Natural Step (The Natural Step, 1991)	This theory describes the concept where all natural processes (including humans) can fulfill their basic needs and where the **extraction of raw material and creation of unnatural material is minimalised.**
Industrial Ecology (Graedel, 1994)	This theory is seen as the toolbox for sustainable development. A concept that combines **the technosphere and biosphere** and aims to minimise energy use, material consumption and environmental impacts along the lifecycle of a product or service.
Regenerative Design (Lyle,1996)	The design of processes that **restore, renew or revitalise** their own sources of energy and materials.
Biomimicry (Benyus, 1997)	An approach of sustainable solutions to human challenges by **looking at the methods of nature and imitate that.** Taking nature as mentor.
Cradle to Cradle (McDonough &Braungart,2002)	This theory is based on the ideas Waste=food and to celebrate **diversity.** Eco-effectiveness should be more important than eco-efficiency. Use solar income and separate the bio- and technocycle.
The Doughnut economy (Kate Raworth,2013)	The Doughnut describes the social and **planetary boundaries** in between lies an environmentally safe and socially just space in which humanity can thrive.

Table 2.1: Theories that have similar ideas about the circular economy Based on :(Leising, 2017)

2.2 The outline of the circular economy

The most common and most used definition of the circular economy is the definition by the Ellen MacArthur Foundation and is explained through the butterfly diagram (figure 2.3). This diagram shows that materials are separated into two separate cycles: the techno-cycle, recognised by the blue lines, and the bio-cycle which is recognised by the green lines (Ellen Macarthur foundation, 2015). The distinction between these two cycles helps us to understand how materials can be used in a high-quality way so that they can properly be separated from each other after their service life. The main message for both cycles is that the fewer process steps a material has to undertake in order to be re-used, the more embodied energy can be saved. There are mainly four fundamental ways to deal with materials in relation to the circular economy. These are presented in figure2.4.

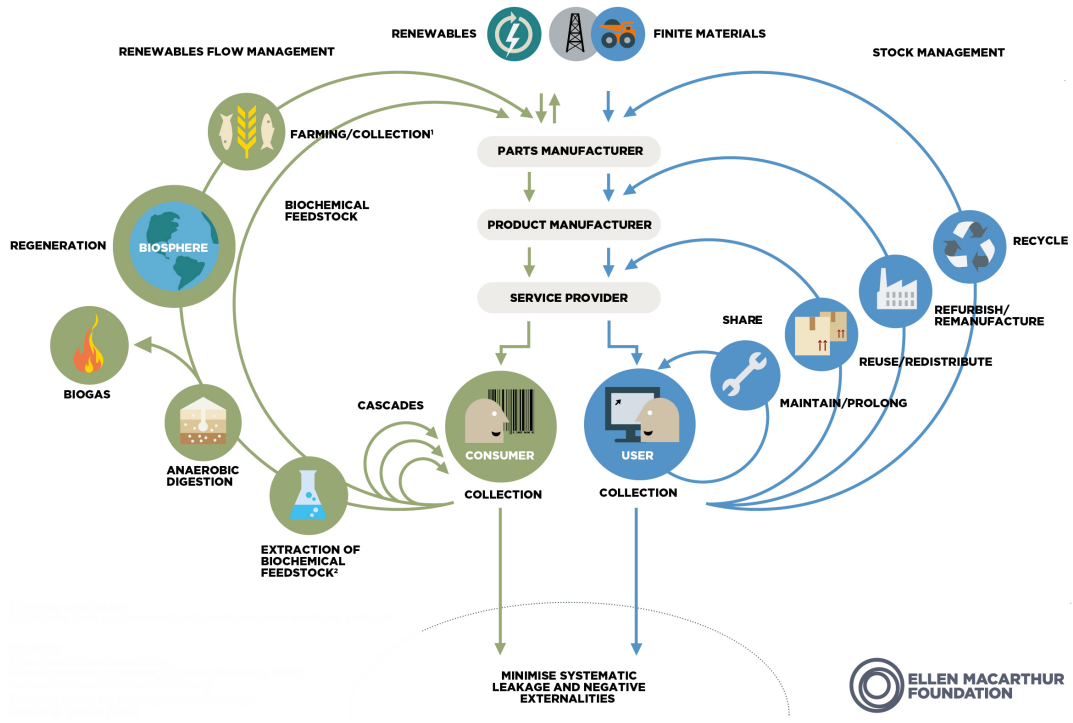


Figure 2.3: The butterfly diagram. Source: (Ellen Macarthur foundation, 2015)

§2.2.1 **Power of the inner cycle**

This fundamental principle shows: the tighter the circle, the less embodied energy will be lost, as stated before. The more the loop of the circle expands, the more energy, time, and resources have to be invested to achieve the same value. The ideal sequence is to extend the lifespan of the material, through repair or maintenance. The second most ideal is direct reuse or redistribution by re-marketing a product. The third most ideal is to remanufacture or refurbish. The least ideal is recycling.

Within the technical cycle the preference order is as follows:

1. Design for Maintenance

It should be easy to repair or to maintain the building components. The structure should allow for removal and replacement of singular components.

2. Design for Reuse

Extending the lifespan of a complete building or component at the end of its functional life cycle by giving it the same or different function through reuse.

3. Design for Remanufacture

The third scenario is about remanufacturing components at the end of their functional life cycle. The quality of the components after remanufacturing should be identical to the original.

4. Design for Recycling

Components and materials should be designed in such a way that they can easily be recycled into new products or cascaded for downcycling.

§2.2.2 **Power of circling longer**

Keeping the products usable for longer or ensure intensified use within the same cycle avoids excessive material, energy and labour usage of creating a new product or component.

§2.2.3 **Power of cascaded reuse**

The principle refers to diversifying reuse of biological materials through other applications, which is called downcycling.

§2.2.4 **Power of pure inputs**

Uncontaminated input of raw materials increases the efficiency of the collection and redistribution process of the materials after use. This principle ensures material longevity.

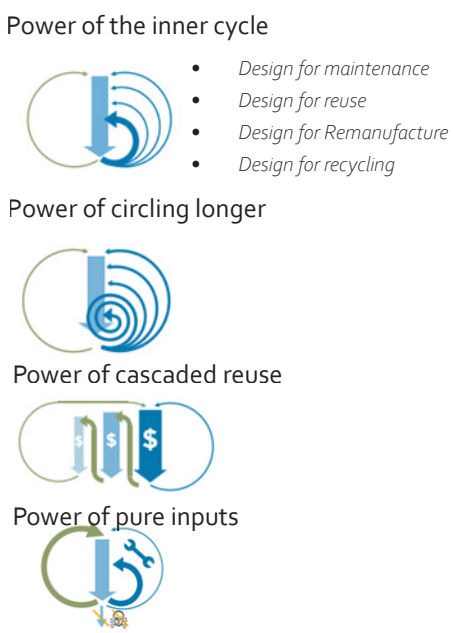


Figure 2.4: The four fundamental principles og butterfly diagram elaborated.Source: (Ellen Macarthur foundation, 2015)

§2.2.5 **Biological cycle**

Within the biological cycle, renewable materials and biological nutrients can be recycled by following four steps: Cascading, biochemical extraction, anaerobic digestion ,and composting (figure 2.5). A definition for renewable resources is stated as follows:" Resources that can be harvested or renewed on a regular basis." Examples are timber or bamboo. This is possible as long as the right conditions for the production of these materials are maintained (Berge, 2000).

Cascading

Biological materials degrade over time and therefore they lose their quality. It is desirable that these materials decline along the cascade to utilise the stored energy that remains.

Biochemical extraction

During the second scenario the biological materials are brought to a biorefinery, where conversion processes are applied to the biomass in order to generate electricity and process heat fuels, power and chemical products.

Anaerobic digestion

Biological materials are decomposed by microorganisms through a process of anaerobic digestion, whereby biogas, that can be converted into electricity, is produced.

Composting

Natural microorganisms such as bacteria, fungi, and so on, can turn the biological material leftovers into compost. This way biological nutrients are returned to the soil, and enable new plants to grow whereafter it can be collected and manufactured into new organic materials.

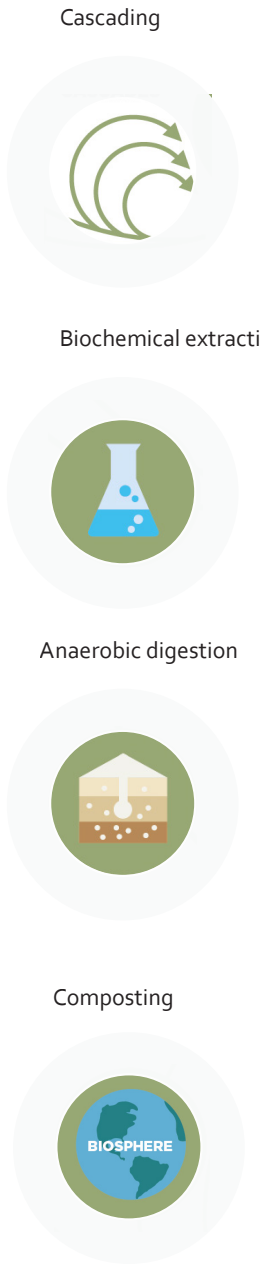


Figure 2.5: The biological cycle. Source: (Ellen Macarthur foundation, 2015)

2.3 Circular strategies

In the last paragraph different strategies to restore the pressure on earth's life-supporting systems have been described. In this part of the report several examples applied in the building industry will be given and illustrated with examples projects. The following approaches used for building projects will be discussed: new buildings out of reused materials, design for disassembly, design for adaptability, design out of renewable materials.

§2.3.1 New buildings out of reused materials

Reusing building materials saves on newly mined materials and further processing. Building components that are suitable for reuse do not need to be remanufactured but can directly be used for the same or for a different function.

The challenge to use reused materials is to find suitable building elements, components, or materials in a relatively close area around the constructed building's location. At the moment, harvest websites are upcoming. By using these harvest websites, projects can place and find donor material within the desired location range. In this way designing new projects out of donor material already becomes more feasible. However, from a managing perspective, it would be ideal if these excess materials will be shown on the donor website a certain time in advance, so already in an early stage of the design process, these donor components can be integrated.

In future building projects, reuse can be stimulated when a certain form of modularity is being used in the design. Also, standardised dimensions or connections can help.

An example

The ambition of the architects for this project was to realise the Villa Welpeloo by 2012Architecten with excess building materials from the surrounded area (Figure 2.6). In order to find excess material 2012Architecten has made use of a harvest map .This shows materials and components that are ready for a next user life. As the location of these materials are also shown, it is possible to choose from a certain region. The platform is filled by a specialist team that finds and locates these elements/materials.

For the structural elements of this house, steel beams were used of an old textile machine that was found in the surrounded area. While timber of old rope coil was used for the façade. The timber has been heat-treated to improve the quality of the wood. The process of heat treating of timber is as follows: heating, drying, grinding and steaming. Hence, no additional coating is needed which is favourable for the end-of-life scenario of the timber panels. As the architects wanted to make optimal use of resources in the vicinity, the steam for this particular project came from the closeby heat and power station. The approach of using secondary materials is more suitable for single projects, as each donor material that can be found in the area is different, with diverse qualities and dimensions.

The following circular aspects can be found in this project:

- Reducing the need of raw materials by design and built with secondary materials.
- Making use of a harvest map to find donor material in the area to minimise transportation.
- Minimise coatings and permanent adhesives to allow the biological material to cascade after use.
- Minimisation of manufacturing energy by using the steam from the heat and power station.

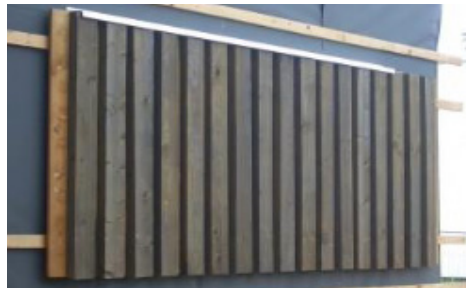


Figure 2.6: Villa Welpeloo in Enschede and examples of reused elements(Jensen & Sommer, Building a circular future, 2016)

§2.3.2 Design out of renewable materials

Reducing CO_2 emissions is high on the agenda of the Netherlands. Renewable products can help to achieve this goal. Where biobased products are used, more polluting alternatives are avoided. Furthermore, these renewable materials have the potential to grow back after harvesting. Only 2-3% of pure timber-frame construction are used in the housing market in the last decades, but a growing amount of housings use a mixed construction from timber frame parts, sloped timber roofs, floors or prefab cavity walls which in total adds up to 15% market share (NIBE, 2019). NIBE(2019) has analysed the potential for several other biobased products (share of 0.1%) such as reed, flax, hemp, bamboo, tomato plants, algae and straw. Although there will not be enough biobased material to replace the technical material loop completely, the share could be increased to 50%, resulting in an average reduction in the *MPG score of 20%.

A building out of biobased materials

Strotec works with timber frame construction that is insulated with straw (figure 2.7). The prefab elements can be seen as timber frame crates filled with pressed (4 ton) straw. By screwing these boxes together, a strong whole is created. It is possible to stack these panels on top of each other without the need of an external construction up until three-building layers. For low-rise buildings, a semi-prefab construction method is used. The exterior layer and windows are placed after the construction is placed. The foil that functions as a water barrier must then be wrapped around. The elements can also be demounted to take the materials apart for the end-of-life scenario (e.g. cascading). It already has a European C2C (cradle to cradle) certificate. The construction itself is vapour open, and the inside of the panels are finished with loam. Combined together, the system has a high permeability. A 50-year guarantee is assured for when the panels are dryly stored. The panels are susceptible to water, and they must be prevented from being soaked wet during installation. The construction needs to stay vapour open on the exterior side of the construction. More information about this system can be found in Appendix B.

Figure 2.7: Strotec facade panels source:(Ecocon)

*MPG: MilieuPrestatie Gebouwen: The MPG is an important measure of the sustainability of a building.

§2.3.3 Design For Disassembly

This approach intends to design complete buildings or building elements that are easy to disassemble in individual components or elements that allow for the separation of materials. The opportunity for disassembly makes it possible for the component to be reused, reassembled or eventually recycled into new products of similar or higher quality (Jensen & Sommer, Building a circular future, 2016). The two main focus points to make the reversible product are: The connection should be demountable without damaging the other components. The quality of the material should be durable enough to last another lifetime. More about this approach can be found further in paragraph 2.5.

An example

The Ferlem house of the company Ferlem international is a project that is mainly designed with design for disassembly. The system is a variant of the structural insulated panel system (SIPS). The building components are prefabricated with all functions integrated, such as thermal insulation, and are self-supporting for fast and easy assembly on-site. The facade system consists of two separate panels, the exterior wall element and the interior wall element, that are placed in succession to each other. The interior wall element has integrated a specially designated place for electricity and water pipes. In this way, options are kept open to adding the necessary wires needed in the future. However, it is not possible to change the inner wall or any other wall after completing the project as it is interlocked with the floors and panels next to it (further information can be found in appendix B).

The panels of Ferlem are designed with a set thickness that offers insulation values far beyond the required. Thus, this system is meant for standardisation and will most likely retain its construction and comfort quality in the future. In this way, when the house needs to be expanded, the same sort of panel system would still be able to be on the market while still meeting the future building regulations. However, the sacrifice for the client is the amount of usable square meters, as the thickness of the walls is higher than required.

The house can be disassembled and moved to another location, using the same elements, without the need to disassemble the panels into their components completely. Like Lego blocks, the building can also be expanded by adding another storey on top of the existing house, and vice versa. Panels can be sold to other users if wanted. Furthermore, the client could choose to have a service level agreement with the company Ferlem. It is also possible that Ferlem aids with maintaining and (partly) deconstruct the building when required. This is preferred by Ferlem and in line with the circular economy. The original manufacturer keeps track of their product and makes an effort to gather information on the materials' usage and weathering. However, keeping the whole chain with-

in the same company could potentially lead to a less open market.

The width of an exterior façade panel is 1,0m or 2,0m. This size is easy for assembly and deconstruction. These dimensions are not logical in the building industry, as they normally work in a raster of 600 mm. The interior walls have more choice in panel width variants to allow for more flexibility in the floor plan.

Using prefab elements minimalises waste products, as the elements are fabricated to exact dimensions. The precision of the prefabricated panels is also an advantage for the installation process.

The advantage of the use of SIPS panels is that they can also be used as flooring systems. The floor system is made out of the same materials as the exterior building envelope panels (PUR and MGO board). Hence, the construction is lightweight, which also leads to less material usage for the foundation. In other lightweight projects like the BILT project of Hans Sluijmer (Sluijmer, 2018), circular foundation piles are used that can be removed after the end-of-life of the building.

The materials chosen for the cladding for the Ferlem house are Magnesium Oxide boards. Yet Ferlem has chosen to work with PVC window frames. They have a relatively low thermal transportation value, but with a maximum life span of just 30 years, which is known to be short, they are not suitable for recycling (Asif, Muneer,&Kubie 2005). The limitation of this system is the adaptability level of the whole building. The panels are connected in an interlocking way. Changing just one panel to add another wall opening or adding an extra chamber is not possible without breaking down multiple panels. Therefore, this building method is not well suited for design adaptability. The following circular aspects can be found in this project:

- Integrated space for electricity and water circulation in the walls.
- Lightweight buildings can minimise the needed foundation dimensions.
- Avoidance of cement in floors saves in CO_2 emissions.
- Division of the wall in an interior and exterior part could provide more flexibility and the possibility for adaptability when they are separable from each other.
- Service level agreement is an opportunity for information gathering and good maintenance.
- Standardisation of dimensions and modularity simplifies the production process.
- Small dimensions of panels make it easy to install and offer more design flexibility.

§2.3.4 Design for adaptability

This concept is a further evolved idea based on a design for disassembly. design for Adaptability is a design methodology that allows users to influence the design of their buildings. Architect John Habraken was the first that applied the Design for Adaptability in the building industry as a reaction to the housing developments after the second world war (Openbuilding.co team, 2019). He proposed the 'open building' concept, where buildings are distinguished in two domains: The building's structure, which the investor more or less defines, and the changeable infill of the building according to the user of the building. Habraken's main point was that mass houses failed because of society's heterogeneous nature, and therefore, the occupants' design decisions should be respected (Geldermans, 2016). And his theory prevents buildings from not fulfilling the current demands while chaos and conflicts that users can create are being restrained with the rigidity of the structure. His book "Alternative to Mass Housing" was first published in 1961 and supported the idea to prevent buildings that do not fulfil the current demands (Openbuilding.co team, 2019).

Design for Adaptability aims to increase the building's lifetime by the possibility to respond to change (Openbuilding.co team, 2019). Integrating flexibility early in the design phase can allow the building to change function through the years. This flexibility can be achieved on different levels. For example, a flexible floor-plan allows for expansion, building modules that can be easily demolished after their service life and upgradable building envelope systems that can adapt to changing requirements, for instance, to allow for the addition of more insulation. Beurskens et Bakx (2015) defined six categories divided into implementation methods, which can be found in table 2.2.

An example

The building " VAN VOLXEM" by Art & Build (figure 2.9) has the current function as an office but can be transformed into a residential building. The design choices that allow this are the large floor-to-ceiling dimension of 3.3m (figure 2.7), the open-plan, toilet blocks, and the heating system compatible with the partition walls for both the offices as the future apartments. The high floor-to-ceiling distance assures better allocation and transformability to different building functions (cpi; Brinkgroep, 2014).

Massive overhanging shading screens are used to reduce energy consumption, and the floor plans are designed to be compact. Terracotta cladding adds to the building's mass that can store energy to react to sudden weather changes. Furthermore, an underground water basin is created to store energy.

Frequency of change		Description	What to achieve with the facade	What to achieve with the facade	How to achieve
High Weekly	**Adjustable**	The capability of the building to **change of tasks**. This can be achieved with non-fixed elements such as plug and play elements or stackable elements, but also detachable connections and operable elements where the user is in control.	Change in sunshading		Plug and play elements User control Non-fixed objects Detachable connections Operable elements
	Versatile	The ability of a building to **change of space**. Examples are movable walls, variety of room sizes, wide corridor widths, frame constructions but also flexible ducts and excess service points.	Change of facade element configuration Change of facade subsystem configuration		Movable divisions Variety of room sizes Frame in construction Flexible ducts Excess service points
	Refitable	Connected to the **change of performance** of the building. A way of achieving this is with standard shapes, dry connections, interchangeable components.	Biodiversity Climate regulation Aestethics change	Vegetation elements Green facade components Air purifier (TiO_2) Integral air/water collection Fauna habitat Outside suscreen Inside suncreen Sun control in the IGU Ventilation Climate facade component Dynamic facade components	Dry connections Standard shapes Interchangeable components Many access points Digital platform
	Convertible	The ability of a building to **change the function**. With a large floor-to floor dimensions buildings, spaces can be transformed easily to the wishes of the user with the use of dropped ceilings, raised floors. Furthermore, simplicity and multi-functional spaces are also key factors.	Window area +/- Doors +/-		Raised floors Dropped ceilings Simplicity &legibility Excess service capacity
	Scalable	The ability of the building to **change of size.** Modularity, excess space, dividable rooms, dividable and joinable rooms are examples of this.	Increase the building size Decrease the building size Transformation of the space	Entire facade to the outside Part of the facade to the outside Addition of a storey Entire facade to the inside Removal of a storey Part of the facade to the inside-loggia Balcony/corridor Changing balconies, galleries into rooms	Local materials Known techniques Modular units Structural reduncancy Extra space on the plot Dividable rooms
Rarely 75 years	**Movable**	**Change of location.** Deconstruct able structures, easy connections, low-weight or adequate sizes are key aspects of it.It can also imply reuse of the building in other buildings.	-Move the total building -Move all facade elements to another structure -Reuse of the facade elements -Reuse of the facade system, subsystems or components		Component scale Collapsable Easy connections Kit-of-parts Component weight Stackable (easy stored)

Table 2.2: Design for Adaptability based on:(Vargas, 2019)

To make the change from an office towards a residential building possible, there are already load bearing points integrated for future balconies. Also, at the core of the building, space is left to increase the structural strength of the building. Furthermore, sanitation blocks of the offices are arranged at one side of the building, which is favourable when turning the plans into multiple apartments. The windows touch the floor to transform them into doors (figure 2.8)for future terraces(Romnée & Vrijders, 2017). Furthermore, the floor is raised to accommodate climate regulating technical installations.

A project like this requires a higher start investment than a traditional office building. The chance does exist that the building will never be transformed into apartments. To minimise the extra costs, reservations are made in the floor plan and the construction. To effectively transform the building, it is essential to have access to the required information and building plans.

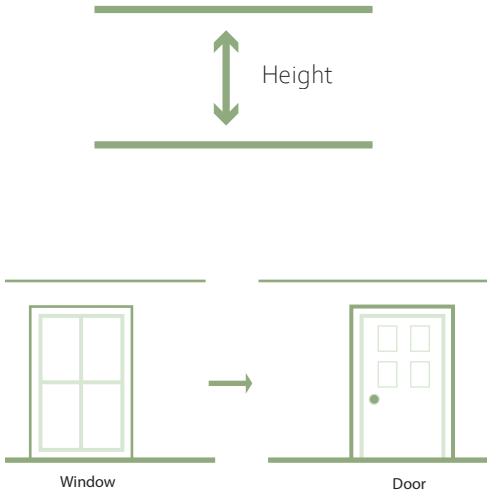


Figure 2.8: Large floor-to-ceiling dimension (top) Transformation from window to door. Own figure

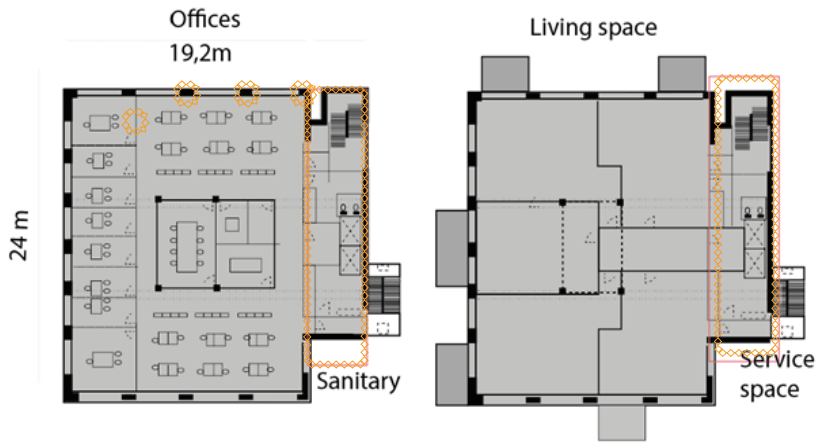


Figure 2.9 : Van Volxem possible balconies and sanitary zones that are placed functionally Based on(Romnée & Vrijders, 2017)

2.4 Distinction in building layers

The former paragraph goes into depth about circular strategies of building projects. This paragraph shows the complexity of interwoven layers in a building that have a different life span.

The theory of Steward Brand(1994) states that a building consists of six layers from the exterior to the interior. The following layers are distinguished: Foundation, Facade, Structure, Services, Space plan and Things (figure 2.10). These components will most likely become obsolete between 7-15 years. When the services are intertwined with other layers it can cause the building to be demolished earlier than intended.

Things
Every layer has its own lifecycle but "things" has the shortest. Examples are furniture and decorations. They don't interfere with the flexibility and reuse of the other layer.

Space plan
Refers to flexibility in the foor plan for the occupants.This flexibility is influenced by the ability of ceilings, walls floors, wet units, kitchen and doors to be modified to changing needs. A turbulent commercial space can already be changed already after three years, while homes might wait 30 years for such a change.

Services
A building should be able to adapt to the changing needs of its occupants. This relates to the flexibility of partition walls and technical systems such as wiring, heating ventilating and air conditioning (HVAC).

Structure
Refers to the construction of the building. The lifetime of these elements is longer than most buildings exist in the built form. It is therefore important that it can be taken out and reused in another building. Adaptability or modularity therefor could be an important factor.

Façade
Refers to the skin of the building. As claddings are exposed to the weather, the service life is usually 30 years where after Exa renovation has to take place or the façade completely has to be changed. It is therefore important that this is made as easy as possible.

Foundation .
The foundation is placed beneath the ground where it is usually not easily accesses able afterwards. The lifetime of this element is longer than the lifespan of several buildings.

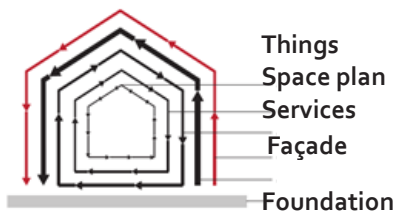


Figure 2.10: Shearing layers of change: Source: (Brand, 1994)

The conclusion of the "shearing layers" research of Brand (1994) is that some layers need to be replaced more frequently during the entire life cycle of the building than others. The problem of current buildings is that layers are sheared so that the ones with longer life cycles obstruct the renovation of the ones with shorter life cycles and the other way around. This can cause damage to different layers when changing one (Berge, 2000). This is a typical problem of housing in the Netherlands built from concrete slabs, brick facades and block-portioning walls and where the installation is mostly fixed into the concrete slabs or walls. This leads to the demolition (of parts)of a building (Durmisevic, Dynamic and Circular Buildings by High Transformation and Reuse capacity, 2016).Durmisevic & Brouwer (2002) made a proposal based on this where elements of the building layers are clustered according to the life span. An element with a shorter life span should be placed close to the surface to maintain easy access (figure 2.11). The building is also assumed to have maximal flexibility for the space plan. However, this method is being argued in terms of systematic and hierarchy of the changing layers. Durmimisevic (2006) presented, therefore, another model called the 'hierarchy of material levels'. In which, besides the functional levels, the hierarchy of sub-assemblies is also defined by material levels. It considers the technical and physical levels of a building instead of seeing it as a hierarchy of elements as Brand suggests. Durmisevic builds upon the research of Eekhout, who defined the hierarchy of building products (figure 2.12), but questions the strict definition of Eekhout as the words system, subsystem, component is relative according to Durmisevic. A subsystem at one level can be a component at another level. Durmisevic (2016) defined three levels of building composition: The building level, the system level and the component level.

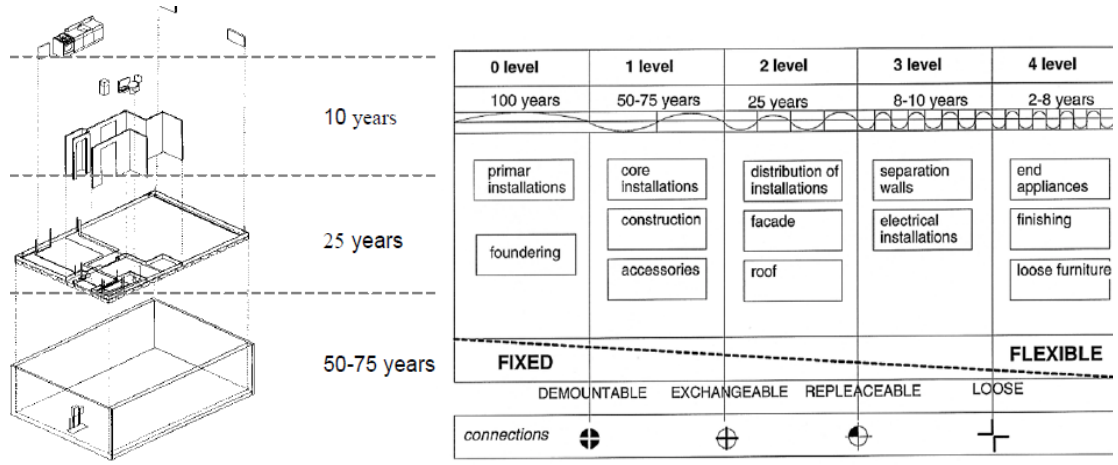


Figure 2.11: Hierarchy of building systems according to the different life cycles. Source:(Durmisevic , 2016)

The building level
represents the arrangement of systems, which are carriers of main building functions (load bearing construction, enclosure, partitioning, and servicing).

The system level
represents the arrangement of components, which are carriers of the system functions (bearing, finishing, insulation, reflection etcetra).

The component level
represents the arrangement of elements and materials, which are carriers of component functions,

being sub-functions of the system(Durmisevic,2016).For example, a facade can have a life cycle of thirty years, while its component parts have varying life cycles between 10-100 years. This suggest that the configuration of the façade has to be independent on functional level from the components of this facade. So instead of seeing the façade system as a whole as Brand suggest, the façade itself should be seen as a composition of independent parts (Durmisevic , 2016).

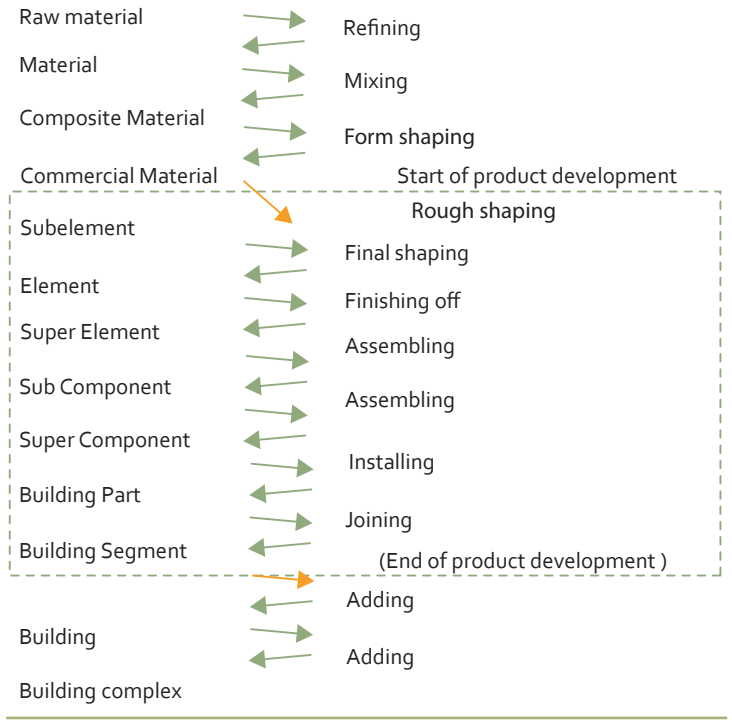


Figure 2.12 : Building product levels. Source:(Eekhout, 2006)

2.5 Existing guidelines for demount ability and accessibility

This paragraph will describe guidelines for building products to enhance demount ability and easy accessibility,
and the choice of materialsto keep them usable for as long as possible.

§2.5.1 **Materials**

The material should be durable and of high quality in order to stand multiple life cycles, but this depends on its functional perfomance. Materials might lose strength, become brittle, are susceptible to wear, can easily corrode, suffer from strain, get discoloured or might in the future be banned because of the chemicals that are inside. Therefore, the material choice needs to be based on the requirements of the element and its function. A few guidelines for choosing the right materials are listed below.

When elements, components or products are designed to be remanufactured, additional materials on surfaces should be added in order for themto be machined or polished during remanufacturing.

Materials based on rare, non-renewable resources should preferably not be used in exposed parts of the building. As loss of material can occur due to wear and tear (Berge, 2000).
The material should preferably be from a renewable source to provide nutrients for new material life cycles by cascading.
Or it can be from secondary origin to save on raw materials.

An unnecessary layer, like some coatings, can complicate remanufacturing or recycling from other components because of debris. The chosen materials need to be coherent with one or more life cycles.

Before reusing a component, it is necessary to check its quality. To make this process easier only primary and secondary mono-materials should be used. A primary mono-material is a single homogeneous material used in its natural state such as untreated wood. A secondary mono-material is a mixed material such as concrete, glass, or cellulose fiber. An example where the problem arises is in prefabricated building elements where cladding, insulation, and structure are integrated into a single component and thus where different levels of decay can be identified (Berge, 2000).

§2.5.2 **Components and connections**

The same as with materials, the components and connections are also important for a non-destructive, disassebly and reassembly process. In this part of the thesis a few guiding lines are given

Number of connections

To assemble and disassemble fast, it is recommended to use a minimum number of different types of connection and fasteners, which can be used in combination with standard available tools(Figure 2.13). This strategy makes repair or disassembly a more approachable process.

Geometry of product edges

Disassembly sequences can be affected by the geometry of product boundaries related to the interface design and specification of the connection type. Figure 2.14 illustrates six situations that define the suitability of geometry for the disassembly of components. A distinction can be made between open and interpenetrating geometry. Interpenetrating geometry is less favourable for disassembly as it can only be disassembled in one direction or needs to be demolished, which implies harm to the connected elements.

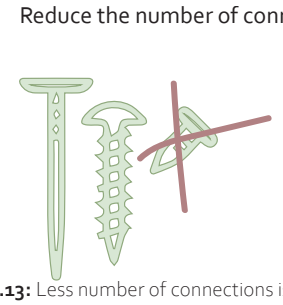


Figure 2.13: Less number of connections is better. Source: (Durmisevic , 2016))

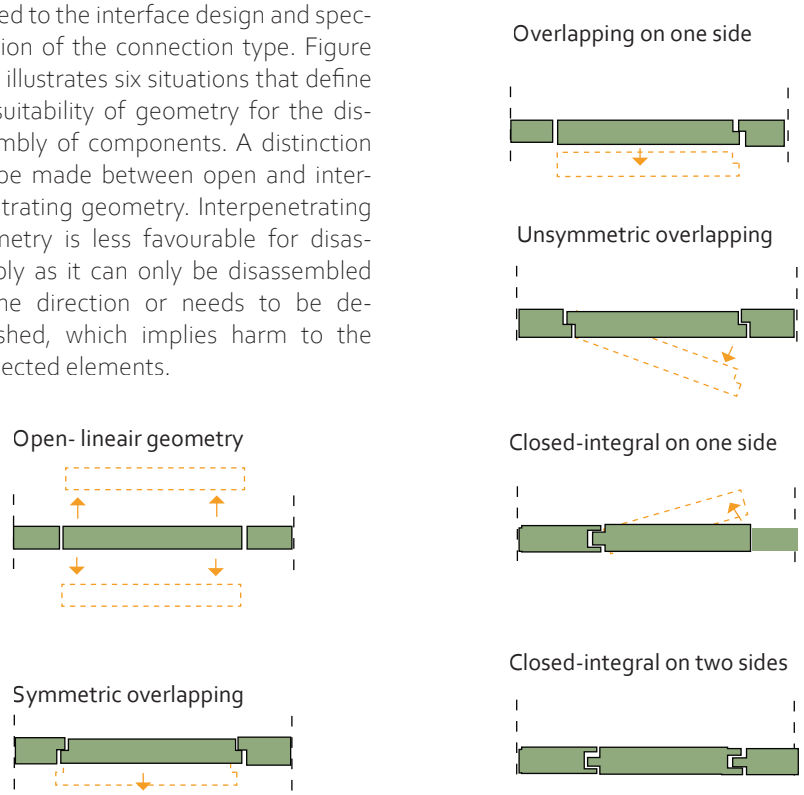


Figure 2.14 : Typologies of product edges. Source: (Durmisevic , 2016)

Permanent connections

Permanent connections should be avoided just like connections that fill the space between two components with a chemical material (figure 2.15). This in order to separate the materials after the end-of-life or in case of replacing one component. A more flexible connection method is recommendable to allow for easier disassembly.

Avoid internal connections

Closed complex hierarchy (figure 2.17) can be described as internal connections, incorporated in between components.This closed complex hierarchy should be avoided as it complicates the disassembly process (edx, Engineering Design for a Circular Economy, 2019).

Standardising

If possible, make use of standardised elements so there is a bigger chance for spare parts being available in the future. This is a method to increase the reusability of materials or building components. Furthermore, standardising stimulates usage in other systems as well. However, to maintain diversity in the built environment, standardised elements should enable assembly in different configurations (figure 2.16).

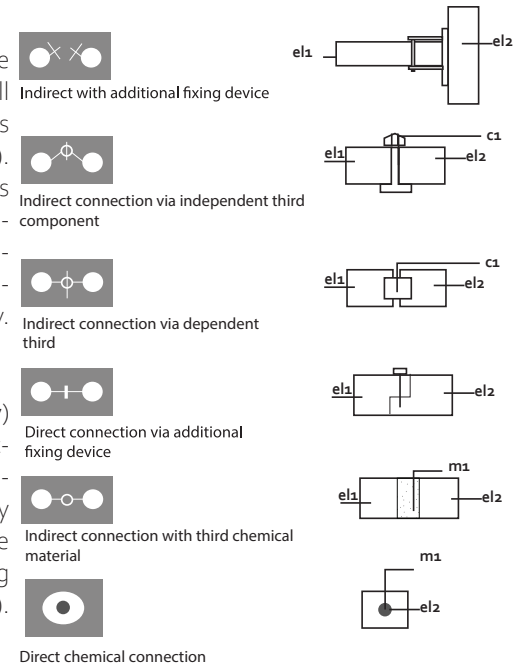


Figure 2.15 : Types of connections and fixations based on: (Durmisevic , 2016)

Figure 2.16: Standardising

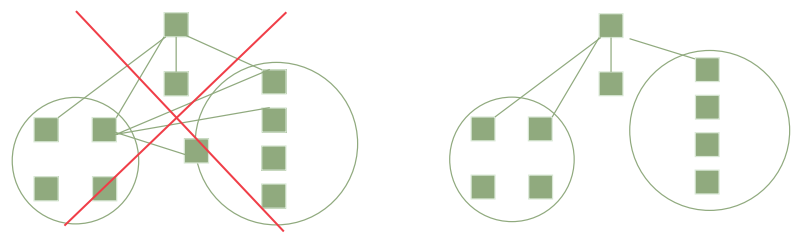


Figure 2.17: Internal connections: Left: closed complex hierarchy, right: open hierarchy (Durmisevic , 2016)

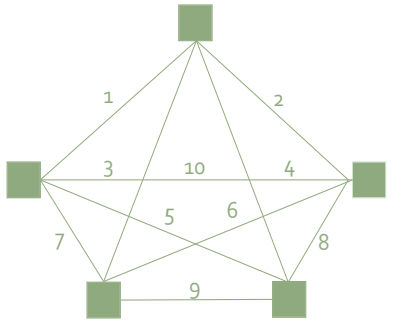
§2.5.3

Systems and structures

The lesser building components integrated into one structure, the easier the disassembly. Furthermore, open hierarchies are preferred as it isolates parts from each other and allows for disassembly (Salama, 2017). Figure 2.17 shows two types of hierarchy a :closed complex hierarchy and a transformable system which contains an open hierarchy. (Durmisevic, 2018). Open systems have a vertical and hierarchical relational pattern. This allows for isolation and separation of products and enables change through disassembly.The relational diagram can be interpreted as follows: horizontally arranged are the relations between different functional groups.While vertically arranged are the technical decomposition within one group (figure 2.17)

Intelligent dimensioning

Dimensions should be suited for the planned function, performance and lifespan(figure 2.18). In order to facilitate future changes in function, over-dimensioning can be an option. Increased material demand upfront can mean a reduction of material demand in the total lifespan of the building when designed and planned intelligently (Geldermans, 2016).



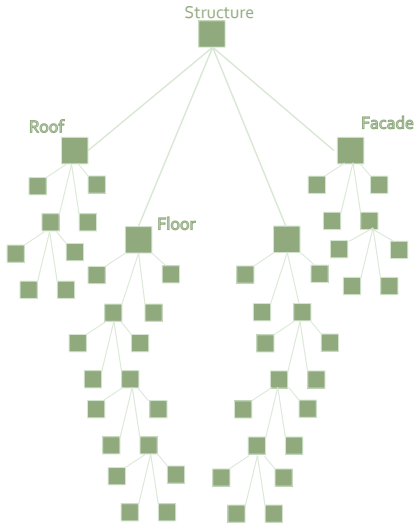
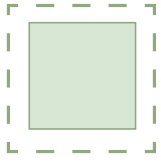


Figure 2.17:Closed hierarchy and open hierarchy based on:(Durmisevic, 2018)



2.18: Intelligent dimensioning (Durmisevic, 2018)

Interfaces

Interfaces between materials and components when disassembling should be in as many directions as possible, to prevent damaging of other components (figure 2.19).

Figure 2.19:Right: Interfaces in as many directions as possible (Durmisevic, 2018)

Clustering

Elements should be clustered according to their lifecycles to make the disassembly process as easy as possible. In this way all the clusters with the same life cycle could be replaced at the same time without interfering with the other elements(figue 2.20).

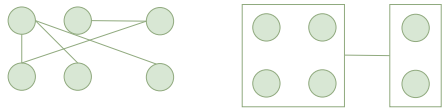


Figure 2.20: Clustering at the right(Durmisevic, 2018)

Separate on function

Separate building components according to function so that replacing components doesn't affect the others(figure 2.21).

Figure 2.21: separation on function

Pre-clustering

Building parts should be pre-clustered in the factory in order to have fewer assembly steps on site (figure 2.22).

Modularity

Modular systems where elements easily can be replaced are favourable.

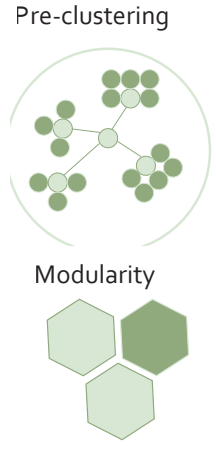


Figure 2.22: Pre-clustering and Modularity. Source: (Durmisevic, 2016)

§2.5.4 **Assembly**

For a product to be disassembled easily, not only the ability to demount is necessary, but the accessibility to the product and assembly order does also play a role. When a product can be disassembled easily this is beneficial for maintenance.

Life cycle coordination

There is a distinction in technical and usable lifetime. A product can be technically in a good condition but not meet the functional requirements anymore and vice versa. Lifecycle coordination means that elements with a long lifecycle should be assembled first and disassembled last. Furthermore, the core element should have the longest lifecycle of all components.

Life cycle related to size

When designing products or clusters, attention has to be paid to the size. Smaller sized components are usually easier to disassemble than larger components due to ease of handling (Ciarimboli & Guy, 2005).

Assembly hierarchy

can be distinguished in mainly two types: parallel sequence and sequential sequence parallel assembly sequence can speed up a building process. While Sequential assembly sequences create dependence between the assembled elements and make substitution more complicated. Durmisevic (2016) has defined five assembly relations based on these two mentioned principles. The arrows in figures 1 to 5 represent assembly direction (figure 2.22).

1. *Parallel assembly*
Disassembly depends on the type of connections between elements.

2. *Sequential assembly*
Each element in this assembly is fixed onto the previous assembled element. In this way a linear dependency is established, which is proportional to the number of assembled elements.

3. *Interlock assembly*
Each element in this assembly has the same dependency as in the sequential assembly (number 2)

Closed circle

This assembly scheme is a combination of 1 and 2. Adaptability depends on three aspects: Function of the elements assembled in the first three sequences

- life cycle of elements assembled in the first three sequences
- Type of connections

5. *Attractor*
One element functions as the base element for all others. The key to adaptability is the type of connection between the distinct elements.

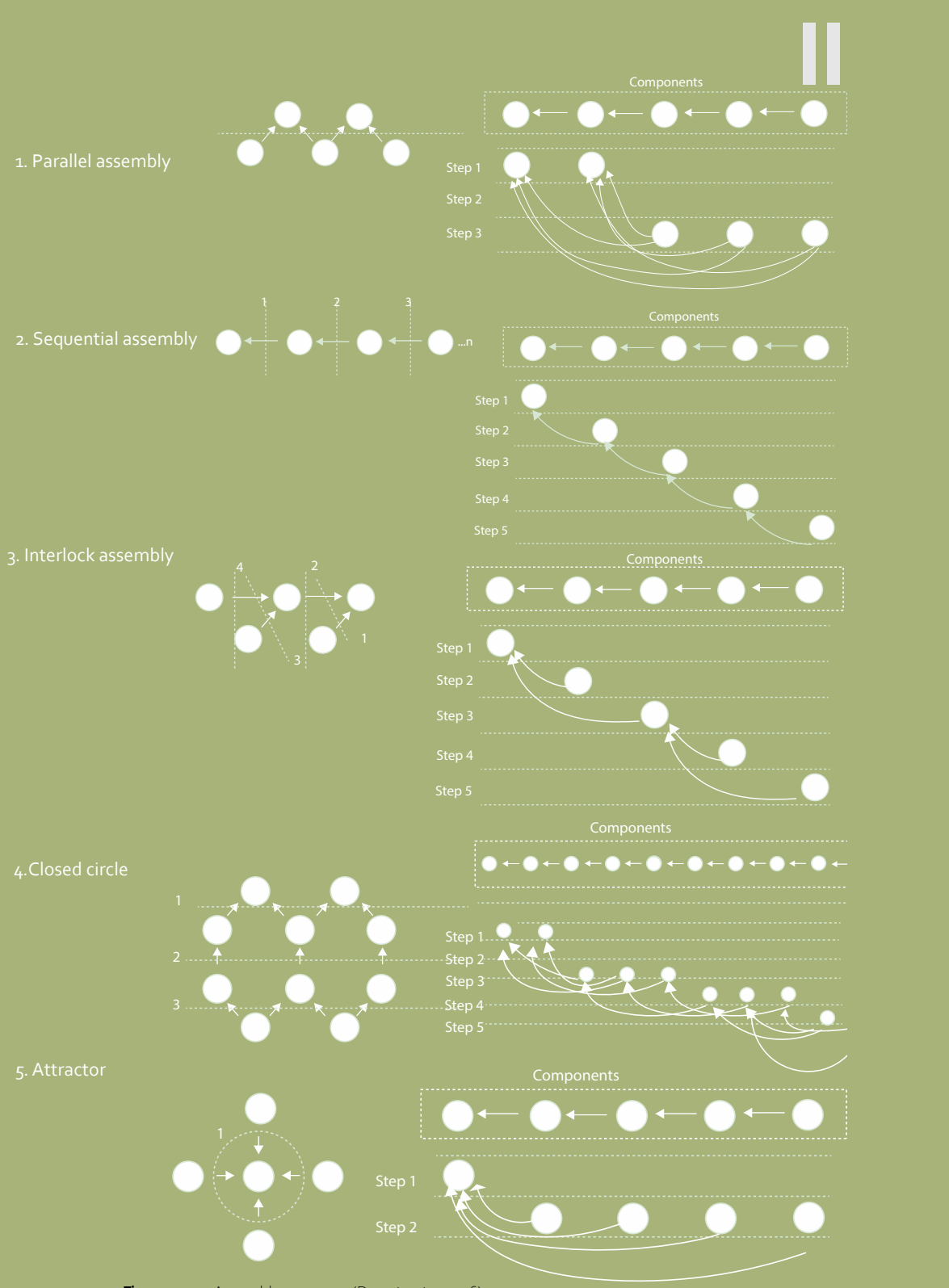


Figure 2.22 : Assembly sequence (Durmisevic , 2016)

2.6 Summary

Since the 1980's many new sustainable system models have been developed to restore the sources of nature. A lot of attention has been given to the reduction of energy production and usage of fossil fuels. However, In the European Union, a total of 2509.9 million tons of waste was produced in 2014 whereof almost 47% ended up in landfills. Mining raw materials to create products adds to the global emissions of CO_2 but above this, the raw material can only be mined once and will not grow back. Therefore, the depletion of materials has to be prevented. An important part to solve the sustainability issue is, according to Wijngaard (n.d.) a circular economy.

According to Yuang, Bi, & Yuichi (2006), the precise definition of the circular economy is not yet commonly accepted but the core of the principle is clear. The principle of the circular economy tries to restore the pressure on earth's life-supporting systems. This thesis divides the principle into three themes. One of the main themes of the circular economy is to stop the need to mine raw materials, the second theme is to close the material cycle by streamlining the mined materials to prevent them from turning into waste. The third theme is to reduce the impact on natural capital. When materials are transformed into products, resources such as fresh water and energy are spent and all sorts of (undesirable) by-products may get released into the environment (soil, water, and air). The most elaborated, used and recognised theory of the circular economy is the definition by the Ellen MacArthur Foundation which has created the butterfly diagram to show how the material cycle can be closed. It separates materials into two separate cycles: the techno-cycle, and the bio-cycle and shows how materials and the embodied energy within can be used to their maximal potential. The ideal sequence is to extend the lifespan of the material, through repair or maintenance. The second most ideal is direct reuse or redistribution by re-marketing a product. The third most ideal is to remanufacture or refurbish. The least ideal is recycling. Within the biological cycle, renewable materials and biological nutrients can be recycled by following four steps: Cascading, biochemical extraction, anaerobic digestion, and composting.

The third paragraph zooms in on circular examples in building projects to apply the closed material cycle theory. The four main strategies are distinguished: new buildings out of reused materials, design out of renewable materials, design for disassembly, design for adaptability, new buildings out of reused materials. The use of secondary materials saves on newly mined materials and keeps the embodied energy gained by processing. Building components that are suitable for reuse, do not need to be remanufactured but can directly be used for the same or a different function. Where biobased products are used, more polluting alternatives are avoided. Furthermore, these renewable materials have the potential to grow back after harvesting. According to NIBE(2009) there will not be enough biobased material to completely replace the technical material loop, but the share of biobased material could be increased from 15 to 50%. Design for disassembly intends to design complete buildings or building elements that are easy to disassemble in individual components or elements to allow for separation of materials. Design for adaptability aims to increase the lifetime of the building by the possibility to respond to change.

The complexity of buildings is the interwoven layers that have a different life span. The ones with longer life cycles obstruct the renovation of the ones with shorter life cycles and the other way around. There are several ways to distinguish levels in buildings but Durmisevic (2016) proposes that the building can be separated into three levels that have to function independently: The building level, the system level, and the component level. For example, a facade can have a life cycle of thirty years, while its parts have varying life cycles between 10-100 years. So instead of seeing the façade system as a whole as Brand (1994) suggests, the façade itself should be seen as a composition of independent parts. The last paragraph sums up technical composition guidelines that allow for the principles of design for disassembly and design for adaptability. The guidelines are given on system-level, element level, and material level. When these guidelines are applied in a design, the potential of using the material to its fullest potential and preventing it from turning into waste due to separation will be enhanced.

Chapter 3

Obsolescence of buildings

§3.1 Preventing obsolescence of buildings
§3.2 Requirements for the technical quality of facades
§3.3 Obsoletion of the current building stock
§3.4 Summary

In this chapter, the requirements that the façade must fulfil in order not to be demolished will be described. Paragraph 3.1 is about preventing obsolescence in buildings. In paragraph 3.2 the requirements for the technical facades are explained. Paragraph 3.3 describes the result of obsolescence in the current building stock. Paragraph 3.4 summarises the findings of this chapter.

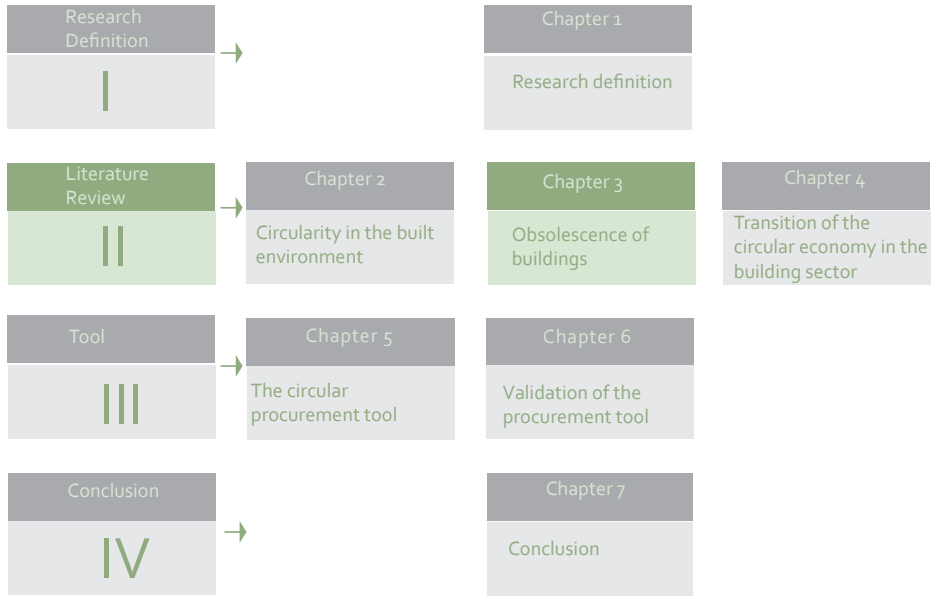


Figure 3.1: Relation chapter 3 in the thesis. Source: Own figure.

3.1 Preventing obsolescence in buildings

This paragraph will describe the importancy of the knowledge of obsolescence in buildings. It is important to understand the factors that determine the life cycle expectancy of buildings to know what factors can cause obsolescence. When this is known, a suitable measure can be taken to prevent obsolescence that results in earlier than intended demolishment.

§3.1.1 Obsolescence

There are endogenous (from the building itself), and exogenous (caused by the environment) factors that influence the degradation of a building. Thomsen et al. (2015) has combined the four main reasons for obsolescence in a quadrant matrix (figure 3.2):

Endogenous physical obsolescence
Degradation of the performance of the building is caused by the design of the building. For instance due to poor or substandard initial quality, physical decay, insufficient strength, or leakage.

Exogenous physical obsolescence
Degradation of the performance of the building that is caused by factors from outside of the building. For example air pollution, acid rain, poor infrastructure, traffic noise, and earthquakes.

Endogenous behavioural obsolescence
Degradation of the performance of the building by behavioural factors within or directly related to the building itself. Examples are behaviour of the main stakeholders, (ab)use, and mistakes in management.

Exogenous behavioural obsolescence
The decline of the performance of the building by behavioural effects from outside of the building. Examples are poor liveability, declining market appreciation but the opposite can happen as well, or failing government policies. In society, this will usually lead to building renovation or replacement.

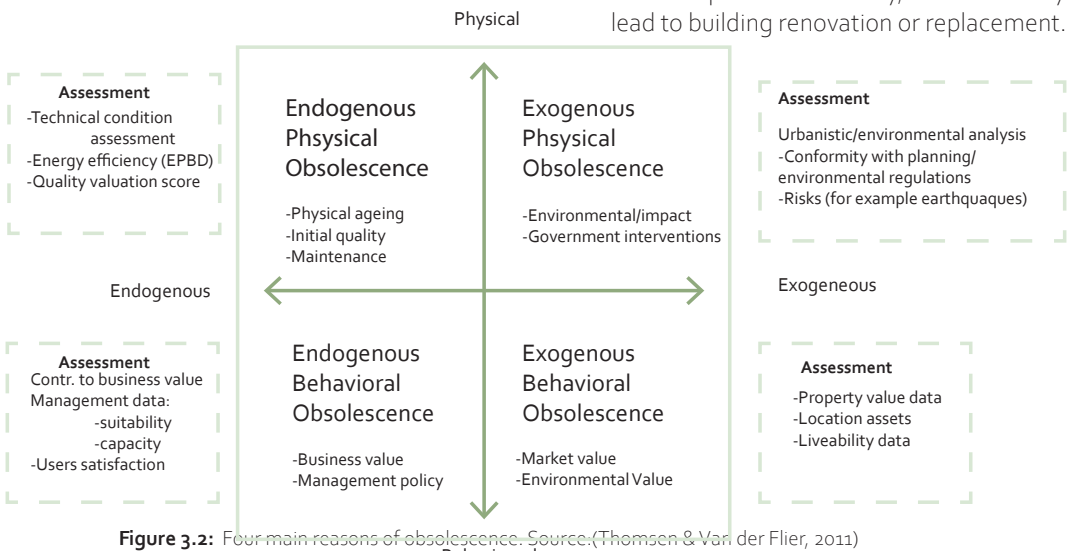


Figure 3.2: Four main reasons of obsolescence. Source:(Thomsen & Van der Flier, 2011)

The work of König, Kohler, Kreissig, & Lützkendorf (2013) have built upon the theory of Thomsen & Van der Flier (2011) and have distinguished more categories of reasons that lead to the obsolescence of buildings. The following are found: functional obsolescence, physical obsolescence, technical obsolescence, legal obsolescence, and economic obsolescence.

Functional obsolescence
When buildings no more fulfil the new functions. An example is the post-war residential buildings with low ceiling heights and deep and narrow plans.

Physical obsolescence
Is caused by poor maintenance and leads to such a high deterioration level that the building is not worthwhile to repair anymore.

Technical obsolescence
Occurs when buildings no longer can implement the current technical standards and repair and replacement is difficult..

Legal obsolescence
This occurs when a building cannot be upgraded to meet the new regulations. Practical examples are insulation for higher acoustics or thermal values. This is also the case when a building consists of dangerous materials such as asbestos.

Economic obsolescence:
This happens when the costs to develop the plot are higher than the income generated through an increased market value. Demolition is almost inevitable in this case (König, Kohler, Kreissig, & Lützkendorf, 2013).

Style obsolescence
When a building is built according to a trend it could lead to an outmoded building in the future. An example is the style of the German 'der Gründerzeit" which was built in the period of economic growth in the late 19th century (figure 3.3).

§3.1.2 Conclusion

Both theories show that obsolescence can have a wide range of causes and is caused by human action (Thomsen & Van der Flier, 2011) Obsolescence can largely be prevented by regular maintenance as well as implementing adaptability. When the building or product is able to change to the new requirements, its value can retain while the captured energy stays intact. For instance, the change of regulations can be a reason why façades have to be replaced if they are not able to adapt. But when the facade is designed for adaptability, through for instance by use of modular design, or through convertible assets, the façade can easily be upgraded. In this way, demolition or replacement of an existing façade may be prevented.

Figure: 3.3: Example of style obsolescence. Source: Kronreif Trimmel&Partner , n.d.)

3.2 Requirements for the technical quality of facades

The building envelope bears many functions to protect the interior from the exterior environment like wind load, rain, and snow. But unlike floors, the facade is also the part the building that needs to connect the interior with the exterior, providing light, ventilation, and view (figure 3.4). Due to stricter legislation on building energy performance, the façade nowadays needs to include technical criteria that haven't been included before (Hartwell & Overend, 2020). An example is to decrease the operational energy of the building. Furthermore, the facade also has an aesthetical responsibility in the built environment. This paragraph will give the required information and details on the technical requirements of facades. When these requirements are understand and met, there is less chance that endogenous physical obsolescence will cause earlier than intended demolishment.

Indoor requirements			
Thermal transportation	Acoustic comfort	Light and view	Infiltration Ventilation Hydratation

Outdoor requirements		
Load bearing and impact requirements	Water/moisture resistance	Fire safety

Table 3.4: Requirements for the quality of façades.

§3.2.1 Thermal transportation

Heat transport can take place in three different ways: convection, conduction, and radiation. For convection a medium is needed such as gas or fluid, conduction can take place in all materials while for radiation no medium is required at all. In the building industry, the insulation focuses mainly on diminishing the conduction of heat, although in some cases it involves restricting radiation as well, as in the case of window glazing. Materials have their own insulation value but the overall rule is: The lower the heat coefficient the better. Porous material generally has a favourable low heat coefficient due to the still-standing air inside but most of these cannot function structurally well. It is thus difficult for a single material to perform multiple functions such as for instance the combination of loadbearing and insulating (van der Linden, Erdtsieck, Kuijpers-van Gaalen, & Zeegers, 2011).

When the construction is partly on the exterior of the insulation, the construction will be exposed to the temperature variations and tensions will arise at the junction of the loadbearing structure and tthe construction on the interior of the insulation (floor). As a result, thermal bridges will occur which will lead to condensation. Therefore, in the vast majority of buildings, the loadbearing layer is on the interior. In NEN1068 windows, window frames doors, and walls have a thermal resistance determined by the building decree.

§3.2.2 Acoustic comfort

The façade should provide adequate acoustic comfort according to the noise level category and function of the interior space. In table 3.1 the values are shown for the acoustic requirements per noise level and function of the room behind according NEN. There are mainly two ways acoustic absorption can take place namely with mass and with a mass-spring construction.

Noise Level	Classroom. living room
I	30
II	30
III	35
IV	40
V	45
VI	50
VII	Requirements based on onsite situation

Table3.1: Acoustic requirements per noise level and functions of the room source(NEN)

§3.2.3 Light and view

Windows and doors are one of the most sensitive and important parts of the façade. Their function is to take care of the energy performance and the environmental circumstances. They form a barrier between the interior and exterior but also connect the two by allowing daylight, fresh air and view.

§3.2.4 Infiltration, Ventilation and hydration

Preventing air infiltration is necessary to prevent unwanted air currents, draft, condensation, microorganisms, odour, and sound nuisance. By constructing as airtight as possible, unnecessary energy consumption is also prevented as the heated air flows through the thermal shell. The minimum requirements are set in the building decree as a qv;10-value and is a parameter in the BENG (1) calculation.

All constructions have dilatations which are in some cases needed to take up expansion or other necessary movements between different parts. The way to seal these places depends on the location of the seal, the material, and the function of the building parts. For this reason, many sealing options are available on the market. Airtight construction starts with well-designed details to avoid air leaks but in practice, this does not always go as planned. The most governing air leaks in practice occur at connections with the ground floor, the connection between the wind frames and facades, corner connections, and the connection of the roof to the facades (Gast, n.d.).

The qv10 value indicates how many litres of air per second, per squared meter facade flows through the building envelope (dm3 / s per m2) at a pressure difference of 10 Pa. The airtightness must be calculated for the entire building. The requirements become stricter as the demands of the energy performance increase.

Ventilation in a building is required for a healthy environment. In a house, this is usually accomplished with grilles, windows, and a ventilation system. The indoor air quality depends on the following aspects. The outdoor quality of the ventilated air, the behaviour of the users, technical installation, furniture, materials, and indoor plants (Böke, Ulrich, & Hemmerling, 2019). Outdoor air pollution is a negative factor in indoor air quality. High-quality air is defined as high oxygen concentration combined with low dust and pollution. The contamination of indoor air is measured in Decipol (Dp) and the CO_2 concentration. Contamination of the indoor air quality can be influenced by smoking and cooking. Furthermore, the higher the humidity and temperature, the lower the air quality. Relative humidity can largely fluctuate between about 20% and 70% and has an impact on health and ambience in interior spaces. Large rooms can easily compensate for humidity due to a large air capacity, whereas small rooms require more extensive air exchange.

To achieve a healthy indoor environment, it is important that the conditions of the above technical requirements are met.Furthermore,the choice of a facade system must be in line with the ventilation concept that will regulate the polluted air and the relative humidity . Air infiltration should be prevented by the choice of facade system that allow for precision. Constructiong as airtight as possible will help to decrease the energy consumption.

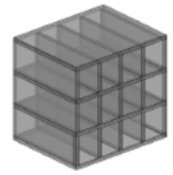
§3.2.5 Influence of the structure on the façade

The structure of a building determines indirectly the function and the requirements of the façade. There are mainly three types of structures according to Meijs & Knaack (2019): Solid,slab and skeleton. They are defined by the vertical elements and the way the roof is supported (Figure 3.5).

Loadbearing external walls
function have the function as structure of the building and to protect against the exterior. The façade in this case carries the weight of the roof and internal floors. Usually the walls are solid and but have small openings that allow air and light. These openings are limited in size by the structural span of lintels (Konstantinou, 2014).

Loadbearing internal traverse walls
Loadbearing internal traverse walls are-also known as box frame or cross walls. This is a method that allow to build very rapid and therefore it became popular in the post war years and used in industrialised and high-rise estates developments. These walls were mostly built from reinforced concrete (both prefab as in-situ) but internal brick masonry walls were also used. The method offers more flexibility for the floorplan as greater building depths can be achieved and lightweight walls can be used. Moreover, it offers more flexibility for the façade to use more and larger openings. (Konstantinou, 2014)

Skeletal frame structure
In skeletal frame structure, the horizontal elements, floors and roof, are supported by columns. Usually the material for this type of columns is either reinforced concrete, steel or timber. This method allows the facade to be fully flexible as the facade is just the infill and not loadbearing. (Konstantinou, 2014). The method has been used since 1890.



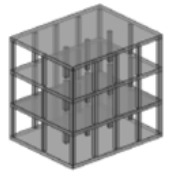


Figure 3.5: Three type of structures: Loadbearing external wall, loadbearing internal traverse walls, and skeletal. source: (Konstantinou, 2014)

§3.2.6 Water resistance

Water is also present in the form of damp in the atmosphere expressed as vapour density or vapour pressure. The amount varies with temperature and saturation. Because of variation of this value, condensation on the surface or interior can occur when the air is colder than the dew point temperature of the surrounded air. In order to protect the insulation from condensation, a vapour proof layer should be placed on the inside of the insulation. Moisture does not form a problem to the insulation if it can evaporate or be transported to the outside before causing damage. When a material has an open structure, which is the case with insulation, it shouldn't be exposed to water as the pores can be fill up. Generally, materials with an open structure are also vulnerable to UV-light. These materials thus have to be protected by a water repellent layer. The position of the water repellent layer is therefore usually the outer layer and should next to repel water also be able to withstand UV. Furthermore, this layer should be easy to clean and should be able to withstand some (mechanical) damage (Meijs & Knaack, 2019).

In some traditional constructions a cavity, which is the space between two construction layers, is used in order to ventilate the moisture away(-figure 3.6). There is always a mechanical connection between the construction layers. The cavity between the leaves is beneficial for sound absorption. When the outer leaf is made out of a vapour-repellent layer, for example, metal, the cavity can prevent condensation buildup and prevents moisture from reaching the inner leaf. Because the air between the two leaves is moving due to temperature variations, the moisture can be transported to the outside. The cavity is because of the moving air, not a great insulator. To prevent water penetration from the roof to the insulation, the roof also needs to have a water repellent layer. When the roof has a slope this layer can be open for vapour diffusion. However, when the roof is flat, it requires a vapour tight layer as it will not runoff quickly enough (Meijs & Knaack, 2019).

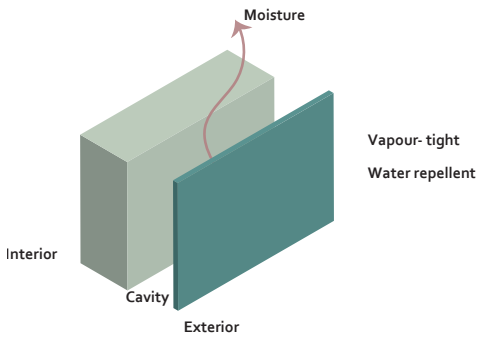


Figure 3.6: Cavity wall. Based on (Meijs & Knaack, 2019).

A prefabricated option is the sandwich panel, which has thermal insulation in between the exterior and interior layers(figure 3.7). The exterior layer is waterproof, resists UV radiation, and can withstand some mechanical impact. The interior leaf should either be vapour-tight or an extra layer between the interior leaf and the thermal insulation should be vapour tight. This construction method is susceptible to moisture when applied as a roof because of the connections between the sandwich panels (Meijs & Knaack, 2019).

Another approach is to build with damp open materials(figure 3.7). Moisture can be evaporated to the outside which makes it less likely to remain inside the construction where it can cause mould. In this case, no vapour tight materials can be used, not even for the roof construction. From the interior to the exterior more open pores for evaporating have to be used with on the outside a water repellent layer. The insulating materials usually are made out of natural fibers such as hemp, wood fiber, sheep wool, or cotton (Meijs & Knaack, 2019).

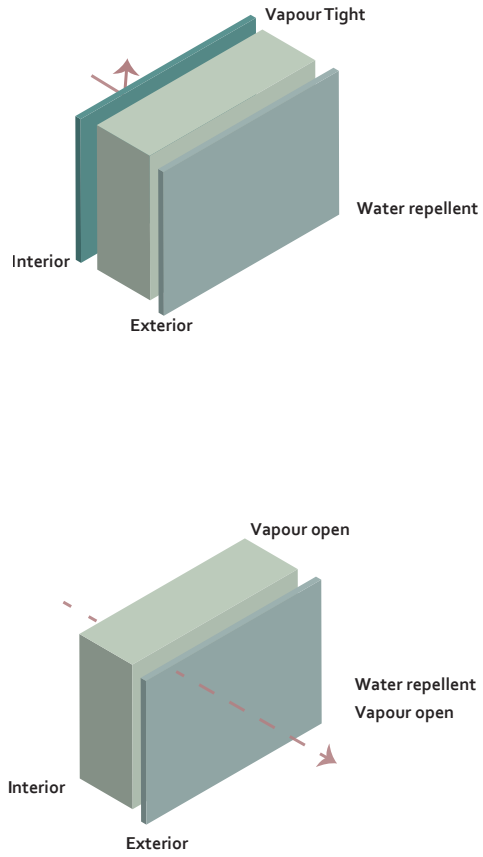


Figure 3.7: Sandwich panel(top);
Vapour open construction (bottom). Based on (Meijs & Knaack, 2019).

- **Spatial formation of the facade**
  - Evironmental benefit
    - -Vegetation
    - -Air purifier (TiO_2)
    - - ntegral water collection
    - -Fauna habitat
  - Enhance the architectural idea
    - -Bridge knowledge gap between stakholders
    - -Allow architectural variety
    - - Support architectural ideas throughout the process
  - Respond to the urban context
  - Create appropriate interior
    - -Choose the appropriate materials and technologies
    - -Arrange components spatially
    - -Design visual, acoustical pleasing
- **Durability**
  - Maintenance
    - -Provide easy handling for the user
    - -Allow for easy cleaning from the user (from the inside)
    - -Allow for facility management
    - -Allow for good access for maintenace and services
  - Rain and moisture
    - -Allow vapour tight connections from parts
    - -Incorporate water sealing system
    - Create internal drainage system
    - Design with suitable material (climate regulation)
- **Energy**
  - Minimise energy consumption
    - -Adapt to changing climatic conditions
    - -Adapt according to oreintation of the bulding
    - -Prevent energy loss
    - -Allow for sufficient natural daylight
    - -Provide sun protection
  - Collect energy
    - - Collect solar thermal energy
    - - Collect solar energy
  - Store energy
    - - Include thermal mass
    - - Include components for artificial thermal mass
- **Comfortable indoor climate**
  - Heating
    - Glazing fraction
    - Shading
    - Solar control glass
    - Light deflection
  - Cooling
    - Thermal insulation
    - Heat insulation glass
    - Thermal storage mass
    - Maintain air tightness
  - (de)-humification
  - Air quality
    - Window ventilation
    - Control air exchange
    - Ventilate excessive heat
  - Visual contact
    - Allow to control visual contact to the outside
    - Allow to control visual protection for the inside
  - Visual comfort
    - - Glare protection
    - - Solar control glass
    - - Light deflection
    - - Control daylight radiation
    - - Allow control of natural lighting of the interior
  - Acoustic comfort
    - - Sound insulation
    - - Sound reduction
    - - Insulation of connection to dividing walls
    - - Insulation to floor conncection
- **Safety**
  - Fire safety
  - Burglar proof
  - Structural loads
    - - Wind load
    - - Dead load
    - - Life load
    - - Thermal impact
    - - Impact load

Figure 3.8 the requirements of the façade based on:

3.3 Obsoletion of the current building stock

In the year 2012, the Dutch building stock counted 7.266.295 dwellings(figure 3.9). The proportion of multi-family houses, in accordance to single-family houses,
differs per province wherein Zuid-holland, that include the cities of Rotterdam and The Hague, the share of multi-family houses is over 50%, while the share in Zeeland is just nearly 20% (figure 3.10). On average the multi-family houses are accountable for 29% of the total residential building stock (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013).

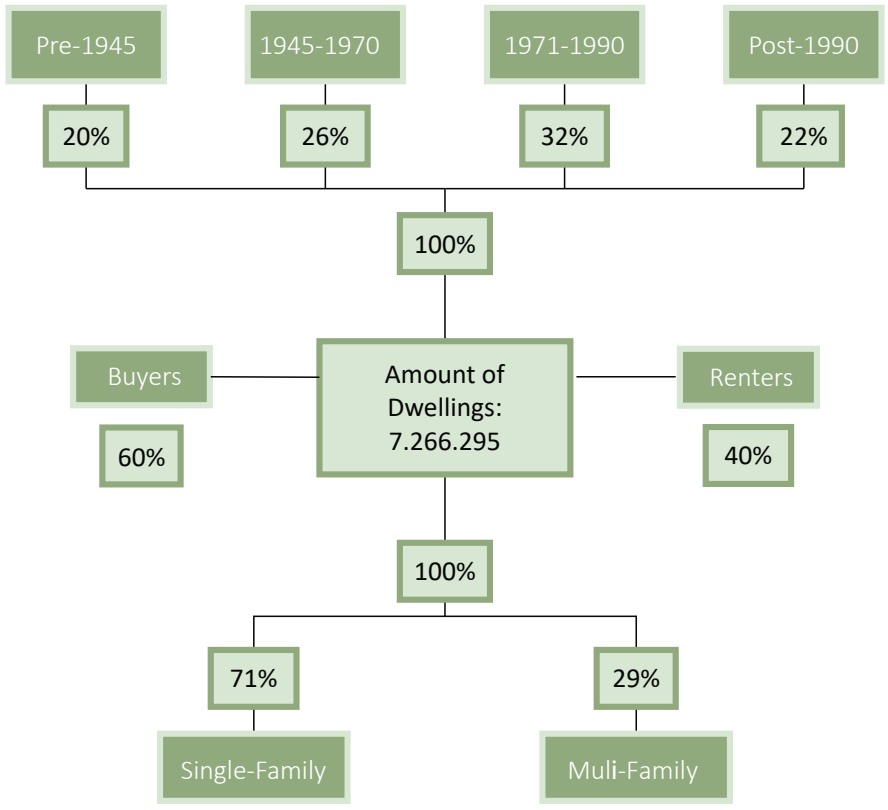


Figure 3.9: Overview of the building stock of 2012. Source: (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013).

§3.2.6 **The renovation market**

Around 20% of the total residential buildings are pre-1945 built. These typologies of dwellings are still popular on the building market but have low energy per¬formances. After the second world war, the building stock had to extend fast to deal with the growing amount of people. In this period,1945-1970, prefabricated building systems were introduced. These dwellings cover 26% of the total building stock in 2012 (Ministry of National Affairs and Kingdom Relations, 2013). System dwellings use an industrialised approach and due to faster construction on-site made they were economically beneficial. However, until the 1970s, dwellings did not incorporate insulation at all and were built with low quality. From 1960 until 1970 the first dwellings with insulation were built, although they consisted of a relatively thin layer. The turning point was the energy crisis of the 1970s that led to high energy prices. In these years the first regulations regarding thermal resistance in the facades were introduced. Taken into account that large interventions of the façade are required after every 30 years in order to maintain the living comfort for residential buildings, all dwellings from before 1990 should either be demolished or renovated (Van Bergen, 2020).

The disadvantage of demolishing the existing stock and replacing it with new houses is besides the difficulty of the relocation of occupants, the sustainability aspect. Replacement by new uses four to eight times more resources than an equivalent refurbishment. With renovating, the same energy goals can be achieved but the construction, can be retained (Itard &Klunder,2007).

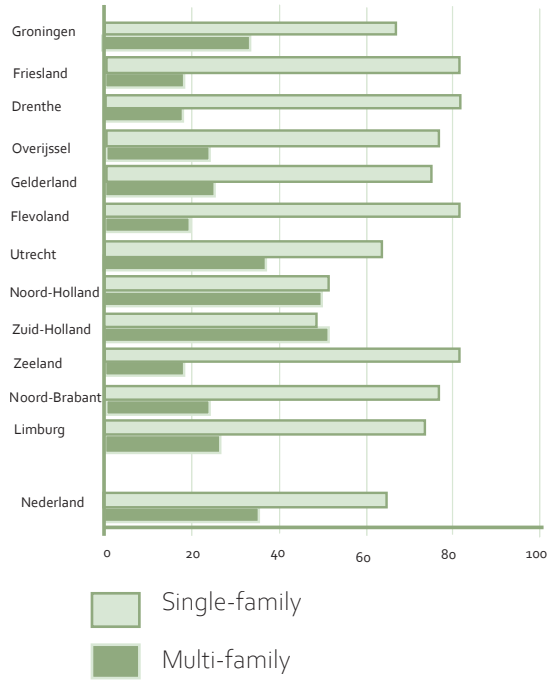


Figure 3.10: Housing type, single family and multi-family houses per provinceSource: (CLO, 2016)

3.4 Summary

Obsolescence can lead to earlier than planned demolition of a building. From a sustainable view, renovating is better than demolishing and constructing new, saving four to eight times more materials. Therefore it is crucial to know how obsolescence can be prevented.

Obsolescence is not only caused by technical degradation, but exogenous factors can also play a huge role. When a building can adapt to the circumstances, and wishes of future users, demolition can be prevented. Regular maintenance is vital to prevent physical obsolescence, endogenous behavioural, and even exogenous behavioural obsolesce. Regular maintenance can help sustain the value of the façade, and a thus bigger chance of preserving the building is achieved. While adaptability allows users to have more influence on the design of their buildings which increases the users satisfaction and can thus prevent endogeneous obsolescence.

The building envelope bears many functions to protect the interior of the exterior environment, like wind load, rain, and snow. Unlike floors, the facade is also the part of the building that needs to connect the interior with the exterior, providing light, ventilation, and view. Due to stricter legislation on building energy performance, the façade should take into account and decrease the building's operational energy by increasing the insulation value of the facade and choosing for small dilatations. A facade system with high precision can help to decrease air infiltration. Furthermore, it is important to have a ventilation system that is in line with the facade concept, such as damp open or damp tight material. This is important to regulate fresh air and relative humidity.

The building's location influences the material durability of the facade by the salinity in the air, sun orientation, the distance and intensity of roads and traffic. Applying suitable materials in line with the environmental conditions is thus of importance to maximise the life of the façade.

The flexibility of the building also depends on the choice of the construction, while adaptability and maintenance can prevent the building from obsolescence. Next to this, the facade system should be in line with the ventilation concept of the building. These aspects form thus boundary conditions for the choice of the facade.

The Netherlands counted over 7.266.295 dwellings in the year 2012. 29% consists of multi-family houses. As most of the buildings before 1970 need to be better insulated and all buildings from before 1990 require significant interventions, the facade is an essential part where circular strategies can be integrated during renovation.

Chapter 4

The transition to a circular economy in the building sector

§4.1 Parties that can influence the building industry
§4.2 Circular ambitions and incentives
§4.3 Methods to stimulate the circular economy
§4.4 The foreseen bottlenecks of the circular economy
§4.5 Implementation of sustainability in procurement
§4.6 Summary

This chapter will answer the following question: "In what way can a procurement method stimulate the circular economy in the residential building sector?" The chapter is divided into paragraphs that focus on a part of this question. Paragraph 4.1 will give an overview of the most significant parties that are influential in the residential building industry In paragraph 4.2, the circular ambitions and incentives that can stimulate the circular economy in the building industry will be set out. Paragraph 4.3 will then show methods that can help to stimulate the circular economy in the building industry. Paragraph 4.4 will set out the foreseen bottlenecks of the circular economy per party. Paragraph 4.5 Will show the implementation of sustainability in procurement. The chapter closes with a summary in paragraph 4.6. The relation of this chapter to the thesis is shown in figure 4.1.

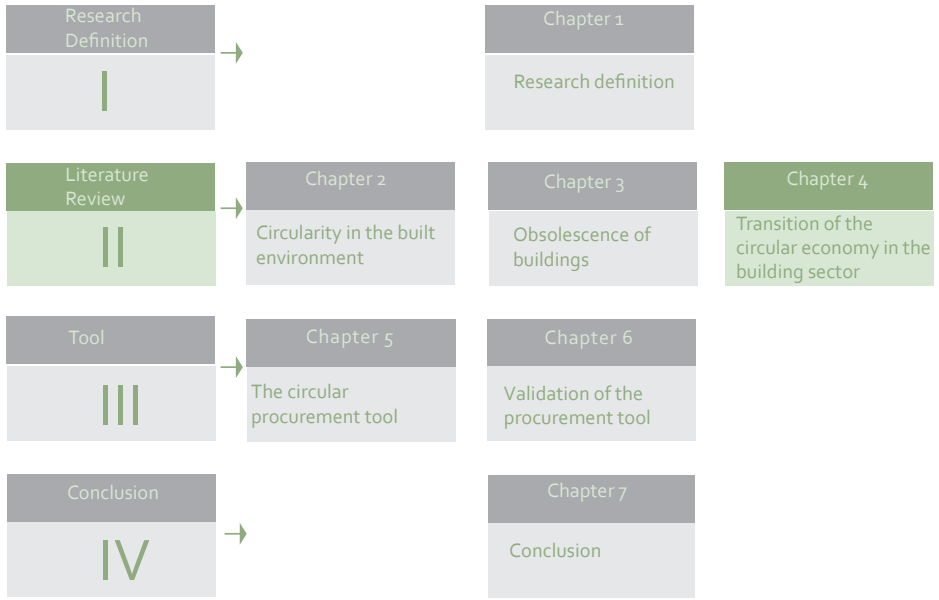


Figure 4.1: Place of chapter 4 in the thesis. Source: Own figure.

4.1 Common stakeholders in the building industry

This paragraph will describe the most significant parties in the residential building industry that can play a big role in the transition towards a circular economy. It is relevant to know how these parties will benefit from a circular economy and how these parties can implement circular strategies into the projects to see how their role will change. This paragraph will answer: Which parties are the most significant for the change from a linear to a circular economy in the residential building industry, and what changes will these parties need to make to accomplish this?

§4.1.1 **Project developer**

The project developer is an essential party as it can initiate circular ambitions in the project through procurement. Two groups of project developers with a significant of Netherlands building stock will be described, social housing organisations and the local owner association.

Social Housing organisations

Social housing organisations are non-profit private enterprises that pursue social goals within a strict framework of national laws and regulations. They are responsible for adequate, affordable housing. Housing organisations perform commercial activities but use their profits to meet general housing needs (Aedes, 2016) even though they can also sell in an arbitrary way (Wassenberg, 2008). Municipalities and social housing organisations are partners at a local level, each with its responsibilities. Housing associations are more stable than the free housing sector because of the guaranteed occupancy of the houses. Therefore, they can have a discounted loan for investments (Economisch Instituut voor de bouw, 2019).

Energy-saving is a current priority in sustainable measures as it can lower the total housing costs of tenants. The tenant group consists of people who get housing benefits from the government and lower-middle-income groups who cannot find suitable housing on the market. Social housing organisations participate in the project' start motor' to stop the existing housing stock from heating with natural gas instead of connecting them to existing heat networks (Aedes, n.d.). During this project, the housing organisations have gained connections, knowledge, and experience with the market and sustainability. Despite this, in the last few years, most development plans have been outsourced to contractors. In-house knowledge is lacking, and leadership shifts towards contractors. When changing to alternative, circular building methods, the in-house experience should again be considered (Kuys & Bergh van den, 2019). All cities contain a severe amount of social housing: 25 % in less populated provinces like Drenthe, 55% in bigger cities such as Amsterdam and Rotterdam, and 30 % nationally (2007, cited in Itard & Meijer, 2008). Social housing organisations have a large amount of housing stock. However,the financial situation forms a bottleneck. Since 2014, housing associations have to pay a large tenant levy to the government, resulting in less money to invest in extra sustainable measures or new buildings (Aedes, 2020).

Group of local owner association (Vereniging van Eigenaren VVE)

The goal of local owners associations is to become more sustainable while avoiding an increase in monthly payments. There are 120000 owners' associations nationally (Twice the amount of houses that are owned by housing corporations). The owner's associations can become more sustainable by choosing high-quality technical sustainable solutions. They can choose products with long service life, prefabricated solutions and also make use of circular business models when renovating. The local owner associations usually consist of volunteers that have a lack of experience in terms of technical, financial, and juridical knowledge. It could be practical for this type of client to encourage module choice with multiple local owner associations, stimulating more mass production or generality in systems (lancering voor de vve, n.d.).

The project developers described above are thus interested in circular aspects that can save in costs in the long run. This implies, for example, a decrease in the operational energy performance of buildings. However, the research of EITClimate-KIC (2019) showed that absence of strategic pressure on national or city-level makes justifying circular procurement performance level difficult and time-consuming. as most project developers do not have the knowledge to demand circularity aspects that lead to a circular, affordable design such as prefab, modular and standardised systems.

§4.1.2 **Architect and engineers**

The architect's role is to integrate and think of circular strategies into the design of the project. With the transition towards a circular economy, integrating circularity into the design will change in the following aspects.

The architect's design should allow for an easy disassembly process to use the separate materials and elements. This change of role includes developing a deconstruction plan by the architect or construction engineer. When considering life span elongation by re-use, a higher impact strength has to be calculated due to extra transportation that attends with reverse logistics. Buildings should function as a material depot, and architects should therefore be able to design with re-used materials. For this to happen, more information is needed to predict or know the material stream. The demolishing process of the old building, for example, should be announced and planned. For new buildings it would make sense to implement a form of modularity in the design and the use of certain standardised dimensions to stimulate re-use.

Additionally, collaboration as the case in design teams and insight into chain partners' products will become increasingly important. The project will require interdisciplinary thinking for this. Furthermore, most circular business models will imply a long-term connection with the product, and the role of the architect could become more of a recurring "circular"-architect (Campagne, 2020). When standardisation in certain dimensions will be embraced by society, buildings can be designed and constructed in consistent ways, helping with better-assured quality and proper re-use. However, a balance between standardisation on a big scale and the need for diversity in the built environment has to be found. Clients may assist the architects on the building's infill design to prevent obsolesce of the theory of Habraken (Geldermans, 2016).

§4.1.3

Contractor

The contractor and supplier will develop new circular revenue models. These revenue models will encourage decoupling of the link between mining raw materials and economic growth. The producer can either be the contractor that combines several suppliers' products or the supplier of part of the facade system. The four most used circular revenue models can be seen in figure 4.2.

Pay-per-use
With this model, the producer earns wages by the usage of the product. The pay-per-use model is only applicable when the product is being shared with multiple people simultaneously, for instance, the sharing of an escalator.

Rental
The customer pays a certain amount to the producer. And the producer ensures the product is available for the customer to use. The risks and the product are, in this case, for the producer.

Buyback
The producer sells the product to the customer and guarantees the user to buy the product back. However, the customer also can keep the product and bears the financial risk until the producer buys back its product. In terms of circularity, Buyback is thus less favourable as less control over the return of materials is achieved.

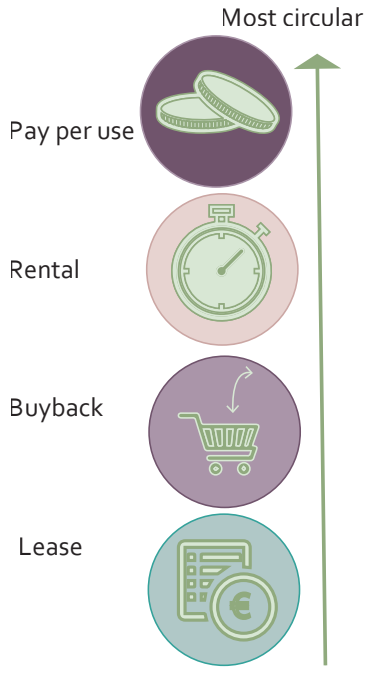


Figure 4.2: How revenue models can stimulate better use of materials Based on :Copper8, 2019.

Lease
A leasing company can be involved in taking the financial risks when the user or producer can't risk themselves. This financial model has the least circular incentives. There are several constructions possible for leasing companies concerning collecting material and parts at the end of life. Lease, however, could be the solution for producers of products with a long lifespan when nor the producer as the producers can finance it (Copper8, 2019).

§4.1.4

Supplier

The mindset "Re-used products are as good or better as new ones" should be encouraged. Re-used products are better than new ones because the manufacturer will also act as a remanufacturer and gain better insight into the use and life span of its products. In this way, it can adjust its design, and the guarantee of the product can be more accurate.

The role of the supplier will change as it could forecast the volumes of material streams in, for example, urban mining and the volume of harvested biobased materials to stimulate innovation with those available materials. Transparent network and process insight will become necessary. to achieve this. Furthermore, long-term relations with clients can become more important. It can improve the technical aspects of the product and in more efficient production and transportation processes. (Circl, 2019).Collaboration between rival companies could lead to a more transparent and better network When designing a product the supplier should take into account the best possible scenario for remanufacturing. The role of the manufacturer will therefore grow and expand in remanufacuring of products. There are mainly three types of remanufacturing companies that are categorised based on their relation to the product manufacturer (Sundlin et al., 2016). The remanufacturer can be the origninal equipment manufacturer, contracted remanufacturer, or the independent manufacturer.

Original equipment manufacturer (OEM)
The OEM can gain all the needed information concerning the product design, availability of spare parts, and service. The remanufacturing process could be integrated with the ordinary manufacturing process, and in this way, the parts from the remanufactured product could be used again. The OEM retrieves its own product arriving from service centers such as hubs or at the end rent contracts.

Contracted remanufacturers (CR)
Another possibility is to have an OEM subcontractor, also referred to as contracted remanufacturer. This remanufacture party is in between the supplier-producer and producer-customer to achieve a bigger production capac¬ity. It usually means that the OEM owns the components but does not need to perform the actual remanufacturing. Because of this, they can offer a consistent production with fewer working capital requirements and risks. Furthermore, the OEM can ask the CR for assistance in terms of replacement, parts, design, and testing specifications. The third possibility it the

Independent Remanufacturer (IR)
Is a direct competitor of the OEM as it can retrieve the parts on its own without collaboration with the OEM. The IR has to buy or collect cores and spare parts for their products to be remanufactured. Typically the IR is a private corporation (Mohamed, 2020).

§4.1.5 **Bankers**
Bankers have a huge role in financing the circular business models. They need to think of new calculation models that calculate the right chances and risks for as-a-service products. Furthermore they have to think about different strategies are needed to help to finance circular start-ups (MVO Nederland, 2016).

§4.16 **Conclusion**
Answering the question of this paragraph, which parties are the most significant for the change from a linear to a circular economy in the residential building industry, and what changes will these parties need to accomplish? The above-mentioned parties that are accountable for the governing residential building stock in the Netherlands are social housing organisations and the group of local owner associations. A part of the social housing organisations has already gained experience in renovating their stock with the main goal of stopping the existing housing stock from heating with natural gas. This implies increasing the energy performance of buildings. However, Social housing, have because of the tenant, levy less money to invest in extra sustainable measures as they have the responsibility to keep their stock affordable. And just as the social housing organisations, the group of local owner association lacks the in-house knowledge to find optimal design solutions that combine sustainability with affordability by, for example, prefab, modular or standardised systems combined with a service contract.

The architect and engineers should start to think of applying circularity in the design that can stimulate reverse logistics by easy disassembly, modularity, and including a deconstruction plan by the architect or construction engineer. Collaboration and interdisciplinary thinking will thus become more important.

The contractor can work with new revenue models that offer the chance to decouple the link to mine new materials with its economic growth by rent, buy-back, or the lease of facades while being assured to retrieve the product back after use. Most circular business models will imply a long-term connection with the product. Additionally, insight into chain partners' products will become increasingly important. The role of the supplier will grow and change in several aspects. The opportunity to forecast volumes of material streams could make more use of the available materials. Reverse logistics will become part of the job, leading to the improved technical design of the product due to better insight into its life span. Bankers and investors have a huge role in financing the circular business models. They need to think of new calculation models that calculate the right chances and risks for as-a-service products. The provided project information could help with this.

4.2 Circular ambitions and incentives

What are the ambitions and incentives of the Netherlands with respect to a circular economy in the built environment? When these ambitions are known, methods can be designed to make it possible to include these incentives to achieve these ambitions.

§4.2.1 **Raw material scarcity as incentive to stimulate the circular economy**
In the past century, the demand for raw material has grown enormously in all sectors, and this number will even be more prominent due to the global population growth (from 7 to 9- 10 billion world citizens). This growing demand will lead to an increase of environmental pressure by the exhaustion of the natural capital. Dependency on other countries for its raw material supply can lead to more geopolitical tensions and supply prices. Together with the signed Paris agreement about lowering the CO_2 emissions, it forms the foundation of rethinking the way we currently deal with our material chain. The Netherlands strives for a decoupling of resource usage from the economic growth and the decoupling from economic growth from the environment. The circular economy is the answer to this challenge to deal more efficiently with our resources (Dijksma & Kamp, 2016).

§4.2.2 **The tight housing market as incentive to build with less nitrogen**
The housing market in the Netherlands is tight due to factors such as population growth, migration to urban regions, an increase in one-person households, low-interest rates and increased incomes, while the construction of housing has lagged far behind because of the last crisis (Ollongren, Nationale woonagenda 2018-2019, 2018). The goal is already set to realize 75000 new homes a year between 2018 and 2021. Out of all new building plans, almost 20-30% of these plans involve mid-rise residential projects. The aim stated in the Bouwagenda is to build in ten years one million homes with as much circular implementation as possible. However, in 2019 The Netherlands granted the authorisation of only 57000 new houses. This was 20% less than the year before because of the government's policy to reduce nitrogen (Programma Aanpak Stikstof (Pas)) .The restrictions of the number of permits will diminish, and the estimated new house permits will be 77000 in 2021 to 80.000 in 2022 and 2023. The net growth will however result in 61000 a year (Koning & Kragt, 2020). This number is however too low to keep up with the growing number of households (see figure 4.3). According to Rijksoverheid (2020), nitrogen pollution during construction is dominant over the user phase. Building with light-weighted and modular elements decreases this deposition and thus can result in the easier authorisation. Other reasons for a lower

authorisation are the shortage of new locations, the transition of gas-free houses, and capacity problems at municipalities and building companies(Koning & Kragt, 2020).

Job opportunities

The circular economy will also offer the Netherlands a lot of new job opportunities. Innovation for existing companies, start-ups, and export chances for (applied) science. The Netherlands can share solutions for scarcity problems, and it offers good infrastructure, main ports, and innovative companies in the recycling industry and Dutch design, etcetera. Also, The Netherlands aims to expand its lead internationally in the circular building industry. Therefore, it is crucial to maintain close cooperation with the European Union and globally (Transitieteam, 2018).

§4.2.2 **Technology**

Many job opportunities will open in the technology sector. Tag systems will evolve to help with pre-sorting processes and coordination for transportation for better time-management on location (VMRG, n.d.). Computer programs such as BIM, where complete building models filled with information can help with planning, construction, remanufacturing, and end-of-life scenarios, will also lead to different job opportunities. Robotics and 3D printing are already reshaping the building industry, and it is vital to make reverse logistics happen. Reverse logistics depends mainly on coordination, logistics, and information availability. Furthermore, to forecast and coordinate material streams in all sectors, artificial intelligence is becoming increasingly important. The feasibility of the circular economy becomes higher with the application of technologies.

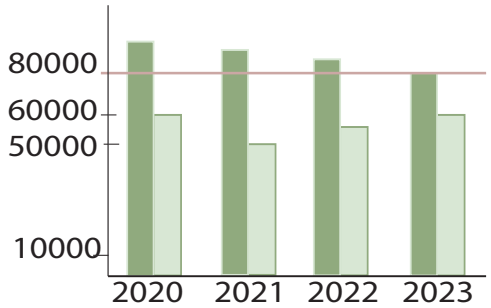


Figure 4.3: Prediciton of the tight housing market . Black line :the abition of 75000 houses a year, Dark green: amount of household grow a year, light green: net expansion of the houses. Source: (Mulder, Meuwese, Bakker, & Nicole, 2016)

§4.2.4 **Potential of biobased materials**

The share of biobased materials used in construction is currently low, while the technical potential is high (DuurzaamGWW, n.d.). However, according to NIBE(2019), the demand for renewable materials will significantly exceed the supply, as the Netherlands is not alone in the biobased ambition, leading to price pressure. Cascading (timber) and using other biobased materials could solve the balance problem (table 4.1). 24% of the wood consumption in the Netherlands is coming from the forest, landscape, and urban greenery. This wood is directly used for power generation. The other 50% for this so-called 'energy wood' is from waste and residual timber and 20% from wood pellets. The estimated European timber production can grow by 50%. Potential is from the forest that is not being used and from the forest currently not sustainably managed. The government supports this idea and is committed to increasing Dutch wood production by stimulating more plantings and sustainable timber harvest according to smart climate forestry (Dijksma & Kamp, 2016). Furthermore, The Netherlands has a leading position in biobased economy and nature-based solutions (Dijksma & Kamp, 2016). The government wants to keep this leading role and stimulate biodegradable applications such as biofuels and initiate them within the national and European product policy. Special attention will be paid to the advantages of biobased and biodegradable applications and the possibility of cascading until it returns to nature (for instance, drilling fluids) (Dijksma & Kamp, 2016).

Material	Market volume [kt/year]	Additional market potential [kt/year]	Proportion
Timber	1200	3173	2,6 X
Straw	0.4	200	500 X
Lignin	-	240	-
Reed	35	127	3,6 X
Cellulose	-	53	-
Flax	2.6	50	20 X
Bio EPS	-	33	-
Bamboo	8.1	14	2 X

Table 4.1 : Overview of the current market volume biobased materials in the building industry ,the additional market potential and the ratio with respect to the current market volume . Source:(NIBE, 2019)

§4.2.5 Conclusion

To conclude on this paragraph, the following question will be answered: What are the ambitions and incentives of the Netherlands concerning a circular economy in the built environment that could be stimulated through procurement?

There is a growing amount for the need for houses in the Netherlands. However, in the last few years, one reason the ambition to build them has not been reached because of the policy to reduce nitrogen. Nitrogen during the construction phase is governing above the user phase. A few ways to tackle this is to build with light-weighted, modular prefab elements. In this way, fewer heavy construction units need to reach the building site. The circular economy can create many opportunities for the Netherlands. One of them is the creation of new jobs. A procurement method could, for example, enhance this effect by giving attention to local companies, start-ups, local materials, and technologies. The Netherlands aims to expand its lead internationally in the circular building industry. Therefore, it is crucial to maintain close cooperation with the European Union and globally. Through procurement, the technology sector that will lead to a more develop recycling industry could be stimulated. A better focus on the material flow can be achieved with Tag systems, BIM, and Artificial intelligence. Furthermore, the recycling industry will be of significant importance, and Reverse logistics, pre-sorting,and remanufacturing will help with achieving this.
Furthermore, the shared interest in timber of more countries leads to price pressure. Nowadays, timber is also used for power generation. As the Netherlands is leading in biobased economy and nature-based solutions, these options should be stimulated as there is a lot of additional market potential, according to NIBE (2019). Cascading and the use of other biobased materials could therefore be enhanced.

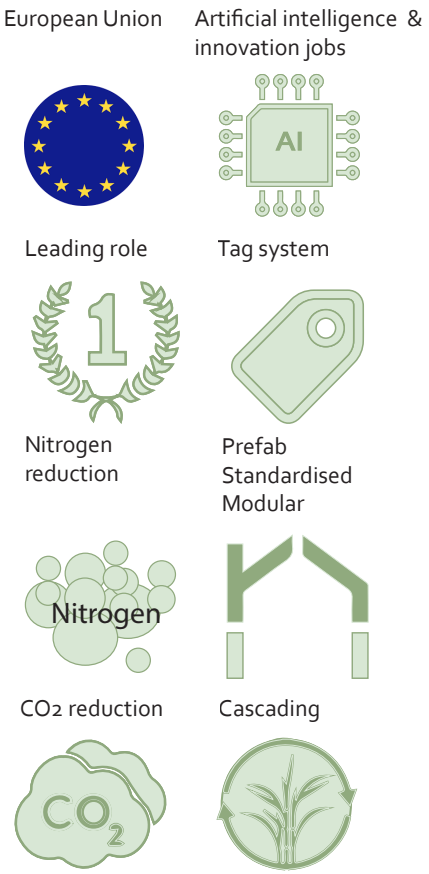


Figure 4.4: Summary of ambitions and incentives to stimulate the circular economy

4.3 Methods to stimulate the circular economy

The previous paragraph the ambitions and incentives for a circular economy have been looked into. The Netherlands has the ambition to become fully circular in 2050 and the role of the parties will change and may increase.This paragraph will show several existing strategies to accomplish specific goals for a building project. Various of these methods can be applied in a tender (Pianoo, 2016).

§4.3.1 Sustainability tools

Parties can use several tools to accomplish sustainability demands for a (residential) building. These tools can prove with the generated results that the building project satisfies the legislation or requirements set above the building decree.

Life-Cycle Assessment

Cycle Assessment (LCA) is a method of analysing the environmental impacts of the whole life of a product. The research of Elia, Gnoni, & Tornese (2016) analyses different LCA's. Some of the analyses concentrate on the flow of materials, while other methods focus on the ecological footprint. It is relevant to understand how one can measure sustainability with different approaches and how the results are combined into scores as the units of the different methods are not the same. The most common is the LCA which measures the impact of a product on the environment and is one of the complete methods that considers human health and the environmental consequences throughout the whole life cycle of a product. The LCA of buildings is less advanced than other disciplines (Khasreen, Banfill, & Menzies, 2009). As buildings have a long life span, it may undergo unpredicted but significant changes in form and function during their lifetime, making them difficult to predict. Also, there are many stakeholders involved with the project, and usually, the designer, who decides the final building design, is not the one who produces the components nor builds the building. As buildings are unique, due to the different stakeholders, there is very little standardization in this field, and new choices have to be made for each specific situation which makes it time-consuming and costly. The LCA also requires data that is not always available. The NEN-EN 15804:2012 is the European standard on how to calculate an LCA.

Milieu Prestatie Gebouwen (MPG)

The MPG is an important measure of the sustainability of a building which is required for a planning application (article 5.9 of the building decree). The environmental impact is expressed in environmental costs, which are called 'shadow costs.' The result of the MPG has the expression: shadow costs / gross squared meter floor. The lower these shadow costs, the more sustainable the project is. The MPG takes the environmental impact of the materials used during the entire life cycle of the building which

also includes demolition and further processing such as recycling.
The MPG is nowadays an integral part of important sustainability instruments. The MPG calculation in the Breeam-NL is included in MAT 8 (Appendix F)but only for office buildings. Credits can be are obtained when the shadow price is below a certain reference value (60%).The reference number is the result result of a building built to a standard level. It is expected that the environmental performance of building materials will become an increasingly important and is meant as an objective tool in the design. (Nederland, 2020).
The MPG should be used in the procurement method to take also the environmental impact of the project into account instead of tendering on the lowest price only (Dijksma & Kamp, 2016).

Nationale Milieu Database
To determine the environmental impact of a single material, a qualified expert performs a life cycle assessment. The Life cycle assessment characteristics can be collected in the Nationale Milieu Database (NMD) to prevent repeating work. When products are stored in this database, they can be used in the calculation of the MPG. The Stichting BouwKwaliteit manages this database. The supplier of the product is in charge of including the product in the NMD.

Circularity indicators
In recent years, various measuring methods for circularity have been developed to be used in a tender (Pianoo, 2016). Examples next to the MPG are the EPG, the CPG, DPG, and BCI. The EPG (Energieprestatienorm voor gebouwen) is a normed method to determine the energy performance of a building , the DPG (duurzaamheidsprestatie) combines both the EPG and MPG into account, the CPG (CircularIteitsPrestatie)takes into account the EPG, MPG and adds the focus on the requirements for a longer life span. Furthermore, a specific method is developed to calculate the Building Circularity Index (BCI) that grades how well the principles of the CE are implemented in a building project by dividing it into three Key Performance Indicators (KPI's), namely:

- the technical requirements of the material and elements
- selecting the conditions of material
- economic drivers to start the Circular Economy (Verberne, 2016).

Important is to consider the differences in the calculation methods between the different assessment for tendering. Measuring leads to a quantitative result. However, in the Building Industry, the "promised performance" can be difficult to demonstrate because the projects that are being requested often have no realised reference that can be used as proof. Furthermore, the assessment is often performed on qualitative criteria, which makes it difficult to make it objective. Market parties, however, indicate that the distinctive character can be found in the supporting plans. Each assessment method described above has its advantages and disadvantages because of its different boundary conditions and focus. For example, the MPG focuses on materials, but circular design principles are not included in this. In the CPG, the circular design principles are taken into account, but prevention of material use is lacking. While in the BCI, no environmental impact is taken into account. There is currently no uniform measuring method that is completely covering circularity in the built environment (Pianoo, 2016).

§4.3.2

Labels
Another way to demand certain sustainability requirements is with the use of certificates. There are many topics for certificates that can function as proof of sustainable topics. One of these topics can be the origin of materials. Examples are the FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification) that conservates the forest's ecological values and ensures that the product with this label is made out of products harvested from sustainably managed forests. While the AluEco- certificate guarantees that the registered aluminium material flow will stay in the Netherlands or Europe. Furthermore, there are certificates such as LEED (Leadership in Energy and Environmental Design), an internationally recognised green building certification system that allows verification through a scoring system and shows how well sustainability measures are implemented. This part will explain a few of the systems as examples.

KOMO quality label
KOMO is founded in 1962 to make complex construction processes more transparent to ensure quality. KOMO is a private and independent foundation and, therefore, not bound to any government. It does not replace any labels or product markings. KOMO certificate holders can already be found in 48 countries and has been objectively tested on relevant legal requirements such as the Dutch building decree, the Soil Quality Decree, the European Energy Performance of Buildings Directive (EPBD), the Drinking Water Decree, and Environmental Product Declarations (EPD, LCA). This is how KOMO can create mutual trust between clients in building and infrastructure on the one hand and manufacturers/importers on the other. Furthermore, it is recognised around the world, which makes it easy to implement the product everywhere. (KOMO, n.d.)

CE label
The 'CE' marking is placed on products traded on the extended Single Market in the European Economic Area (EEA). The label stands for high safety, health, and environmental protection requirements. CE marking also supports fair competition by holding all companies accountable to the same rules. It is therefore mandatory for a product within the European Union. Besides this CE mark, building products also need a work completion statement where the product and addresses of the manufacturers, the importers of construction products, and distributors

must be provided with the product. By having the CE qualification, a manufacturer declares that the product meets all the legal requirements for CE marking and can be sold throughout the EEA. The two benefits of a marking such as CE are that products bearing the CE marking can be traded in the EEA without restrictions ,and consumers can be assured of a certain level of health, safety, and environmental protection throughout the entire EEA (European Commission, n.d.).

Economic incentives

There are several strategies to accomplish specific requirements on buildings. The use of legislation but also through procurement. Certificates can be desired for prestige awards, for proof to regulations, or economic incentives. A well-known financial benefit can be obtained if one can show the residential project fulfill particular demands.

Green declaration

Rijksvastgoedbedrijf also stimulates sustainability with economic benefits on mortgage deduction for investments in sustainable building projects called 'groenprojecten' translated as 'green declaration' in English. To make use of this green declaration, a collaboration between investors, bankers, and project managers are necessary. Buildings that thick specific goals concerning energy performances and other circularity aspects, such as having certificates of building materials, integrating demount ability, and flexibility in the building plan, can get a discount on the mortgage for ten years (RVO, n.d.).

§4.3.4

Summary

There are mainly three ways in which a building's performance level can be demanded. These three ways are either with legislation, economic incentives, or certificates. There are certificates or labels such as Breeam, LEED, and Well what the project developer can use to distinguish the quality of the building project from the buildings that just meet the building decree. These labels are usually meant for high-end projects. However, certifications can be used as proof to show that the project has met the requirements for legislation or economic benefit.

The building market works effectively and avoids more expensive solutions when no sufficient added value is gained with the alternative. Therefore, the third way to be able to demand sustainable requests in building projects is with economic incentives. Besides investing in better insulation to save on energy costs, in the long run, there are also economic benefits such as the green declaration that can offer a discount on the mortgage if it can be proved that the building project will meet the set requirements. Figure 4.6 shows how regulations, economic incentives, and certifications are related to each other. Most certificates can function to prove the demands necessary for economic incentives or regulations.

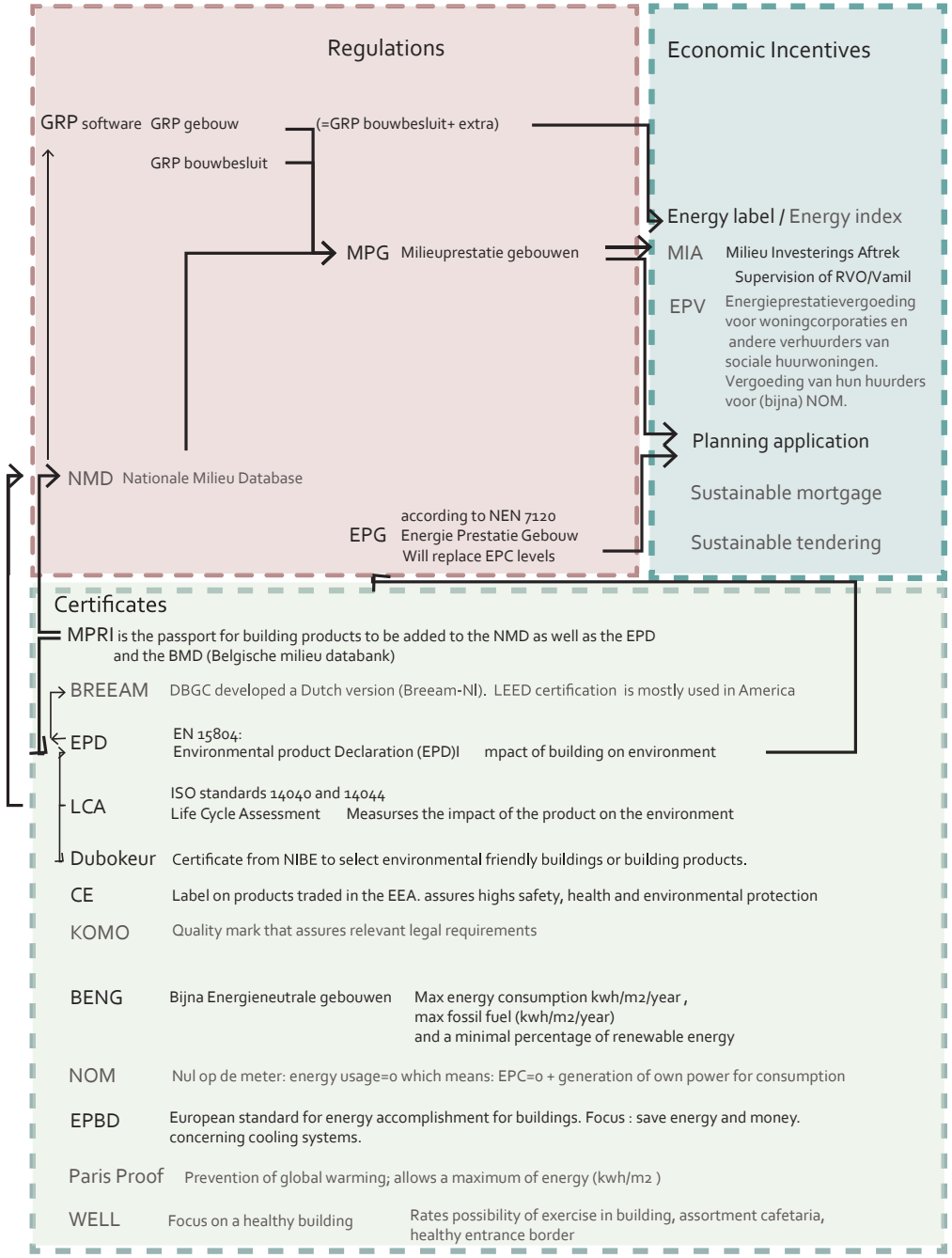


Figure 4.6: Incentives for a sustainable building(Own image)

4.4 The foreseen bottlenecks of the circular economy

The previous paragraph explains the Netherlands' ambitions regarding the circular economy and what methods parties can use to achieve and demand these circular goals in the building sector. This paragraph will show the foreseen bottlenecks of the circular economy that are related to the building industry. The circular bottlenecks will be set out in three main categories: policy bottlenecks, economic bottlenecks, and technical bottlenecks. When these bottlenecks are known, it becomes possible to avoid them. Therefore, an enhanced literature study is conducted to know the most foreseen bottlenecks of the circular economy.

§4.4.1 Policy bottlenecks

The cooperation between governments, companies, science, and consumers determines the success of achieving the circular economy's ambition. It starts with trust and the shared conviction to keep this planet healthy. The government has a leading role. The following policy related bottlenecks are described:Program of the government, restricting legislation , outdated regulations,conservative procurement methods, cirularity indicator in procurement, labels for biobased products, enviromental costs in tenders

Program of the government

The change towards a circular economy is beyond the national level. The Dutch economy is dependent on global resources. Dutch companies operate increasingly on the European level and globally, which implies European cooperation on legislation and regulations to strengthen the market for secondary and renewable raw materials. Next to this, international cooperation is needed to close the chain, internalize environmental costs, and supply security. It is a challenge to find a balance between national ambition and global feasibility.

Restricting legislation

Legislation can either promote or limit the promotion of innovation. There are obstructions in the law that should be removed. While frameworks that stimulate innovation should become more critical (Dijksma & Kamp, 2016). The existing legal frameworks are based on classic production per field but do not allow corporations between different areas for waste streams, leading to an accumulation of obligations and compliance costs. A possible suggestion could be to upgrade the regulations to full circularity for emissions to land, air, water, and companies to innovate towards circular materials and techniques. Furthermore, there should be more space created in the legislation for circular principles in business models (Dijksma & Kamp, 2016).

Outdated regulations

A conceptual framework is needed to grade and label residual flows such as waste and by-products. There is still much uncertainty to define material streams at the end-of-life of products. This is also the case for returned products after refurbishment, repair, disassembly, and recycling (Dijksma & Kamp, 2016).

Circular procurement costs time

Circular procurement will be more time-consuming. It will require to create a planning process from the beginning, it requires the necessary investigations and engaging all the partners (architects, constructors,suppliers) .However it does not neccessarily be more expensive as altough the design costs will be higher, it would not outweight budget of the whole project. (EIT Climate-KIC, 2019).

Conservative procurement methods

Procurement strategies should further develop into data-driven procurement to achieve better transarency as control mechanism. Data should be retrieved from all parties involved. Examples of this data are: pollution rates of the area and quality control of the suppliers. This will help to make a more responsible practice possible where society's future is respected (Circl, 2019). Furthermore, circular ambitions in the project should be set together with the whole network, and broadcasted to the outside world as a control mechanism. This strategy already proved promising results. By sharing a common goal instead of setting limits and restrictions to the supply chain, and improvement in chain network connections can be achieved (Circl, 2019).

Cirularity indicator in procurement

There is a need for a uniform circularity indicator. At the moment, considerable differences exist among the 'circulariteitsprestatie gebouwen '(CPG) of WE Adviseurs and the Building Circularity Indicator of Alba concepts. However, in order to make a weighted decision for tenders, a comparable result concerning circularity should be used (Ollongren, Kamerbrief Maatregelen voor het beorderen van circulair bouwen, 2019).

Labels for biobased products

Biobased products should have a (Dutch) quality mark.In the United States, the percentage of bio-based raw materials is written on the product label and takes into account their purchasing policy in the tendering process which offers transparency as many products are composed of different materials such as wood fibers sheet and non-biobased glue, and other composite materials. (InnProBio, 2020)

Enviromental costs in tenders

Building with concrete has been evolved from World war II a lot of expertise has been gained by most stakeholder and therefor it can be built quite efficient. The building market works effective and avoids more expensive solutions when no sufficient added value is gained with the alternative. There is already some movement in projects of Rijkswaterstaat to translate environmental performance into tendering award criteria but acceleration and broadening to the rest of the market seems necessary (NIBE, 2019).

However,the reward system for choosing a product with a less environmental impact is not economically awarded enough which makes circular products less favourable. The MPG could play an important role in counteracting this, just as the EPC value's growing severance has helped to require higher energy performances over the years. However, the MPG issue is that many existing and innovative products are not inside the NMD. The reason is that start-ups are experiencing difficulties with guarantee agreements and warranties to meet requirements such as fire tests, while obtaining them is an expensive and long process (Dijksma & Kamp, 2016). Therefore, projects will have to choose a less favourable element to enter in calculating the MPG, which makes the shadow cost become unnecessary high. (W. Jansen, personal interview,3 June 2020).

§4.4.2 Economic bottlenecks

The economic bottlenecks of the circular economy are listed as follows: circular economy in the international market, product chain alignment, reverse logistics, business models, the reward system, and CO_2 emissions.

Circular economy in the international market

The circular economy concept is not yet a globally shared ambition. Which makes the influence Netherlands has limited influence in the international market. Not all countries share their interest in raw material export (Dijksma & Kamp, 2016).

Product chain alignment

There is an alignment problem in the product chain. Parties should streamline the materials together. This starts from the mining of raw material to product design and ending with the recovery of the used materials. Currently, the end-of-life scenario is not thought out thoroughly enough (Dijksma & Kamp, 2016). This reverse logistics, where the supply chain moves from the end-user back to the seller or manufacturer to allow for refurbishing and remanufacturing, can be more expensive at first because of the extra cost of labour on a deconstruction plan and process. Nevertheless, in the long run, these extra costs should not form a problem anymore when reverse logistics should be made inevitably for each project by the government with circular tendering (Ellen MacArthur Foundation, 2013).

Lack of continuous scrap material

The approximately 30000 tons of end-of-life post-consumer aluminium scrap a year originated from façade products consisting of a stream with usually the same alloy but is contaminated by the hinges, locks, and material rubbers, glass residues, and insulators. Roughly 80% of the aluminium scrap goes to countries outside Europe because of the cheap logistics, labour, and energy in these countries. Daily fluctuating prices of the aluminium, based on scrap price (LME), forms the reason for not guaranteeing a continuous flow of end-of-life aluminium scrap. Furthermore, the parties that can use the contaminated aluminium mix in the Netherlands within their melting process are limited (Huurdeman, 2017).

There is an internationally organised chain of parties that recycle end-of-life aluminium scrap material. However, the different links in the chain often have too little knowledge of the other parties. The façade-industry is generally on the chain's front and does not know what happens with the end-of-life material. Therefore there is no option to form a recycle chain by itself. This is because the demolition contracture determines how the building material is retrieved, and the scrap processor determines where the material will go. Tough in a niche market, clients are willing to pay more for end-of-life aluminium ('green' aluminium). However, if looking at new revenue models (buy-back guarantee, rent, etcetera), a new possibility of keeping these materials in the sector arises (Huurdeman, 2017).

Another option to keep the end-of-life aluminium scrap in the façade industry is to develop a certification model, to control the aluminium recycling chain. This ensures that the aluminium scrap remains in Europe, making the entire chain benefit more from the high-quality material.

The existing logistics for the recycling chain are already well organised (partly due to existing interest) and should be maintained as much as possible. Looking specifically at aluminium façade products, A/U/F.e.V. in Germany has started an initiative for a certificate to collect and return aluminium scrap collected and returned to the chain- reverse logistics. To improve the material recovering processes in the Netherlands, elements, and components with different lifespans should be separated, and the market should be supply-driven comparable to the car industry instead of demand-driven supply. This allows production based on the product specification and composition (Huurdeman, 2017). The following parties must be included in the demolition industry: recycling industry and recycling companies, smelters, system houses, suppliers, facade builders, and logistics parties for introducing a reverse logistic system.

To maintain the quality of the certificate, the material stream has to be known to assure the volumes of scrap that enter from the certified companies should also be passed onto the other certified companies. In this way, the market based on the scrap price LME is maintained. The certificate must overcome the bottlenecks at the product and process level (purity, logistics, pollution, registration). The research of Huurdeman (2017) shows that closing the chain around end-of-life aluminium scrap at a national level can save up to 83% of CO_2. Based on pilot projects, between 83.7% and 89.4% of the end-of-life aluminium scrap can be recycled into usable raw material. The principles of the AluEco- certificate would guarantee that the material flows registered will stay in the Netherlands or Europe. The materials will be used as high-quality as possible, and the

CO_2 footprint of the chain and material will significantly be reduced. On top of this, partners of AluEco will be able to share innovation and knowledge, and more jobs will be created on regional and national levels (Huurdeman, 2017).

Business models

Barry Commoner wrote the book 'The closing circle' in 1972 with the message of everything must go somewhere. This quote seems logical for ecologic systems, but in financial models, this does not happen yet, which leads to products that are linearly written off to a value of zero at the end of their functional life span. This causes that us seeing and treating the products as waste. The formula determines the accountancy value: (acquisition price-scrap value)/(functional life span). The accountancy value is different from the practical value, as can be seen in the second-hand market. Furthermore, in a rental contract, the product is already written off by 75% of the functional life span. This makes it almost impossible to generate a second life in an own business model. Furthermore, with the revenue model buyback, a ceiling value of 10% of the product's original value (business to business) hinders the incentive. The company can have a negative balance with the business model of leasing as it has to pay tax over the whole product, while it generates, for instance, only income for a short period. It would be better if the company has to pay taxes just when it generates income (Circl, 2019). Thus, there is still too much uncertainty in the new circular business models among both entrepreneurs as with financiers (Dijksma & Kamp, 2016). Circular innovations often have higher capital demands, and sometimes there are longer payback periods involved, as in the case of the product as a service. Due to this let private investors evaluate the risk (unnecessarily) high (Dijksma & Kamp, 2016).

The calculation method for CO_2

The calculation method for expressing Co2 production should be changed for a fair biobased comparison. According to NIBE (2019). More weight should be on the production process and less on possible recycling, reuse, and energy recovery. At the moment, all life-phases are combined in one number but dividing the result per life phase would give a clearer distinction. The proposed method should show the absorption of CO_2 by biobased products as a harmful emission in the production phase and positive in the end-of-life phase. On a total 'cradle-to-grave' LCA, it would not result in a different outcome, but the underlying effects would be visible in the LCA's distinction of life phases.

§4.4.3 Technical Bottlenecks

At last, there are also technical bottlenecks that hinder the linear economy from shifting towards a circular economy. First, the biobased materials will be discussed, then the problem of contaminants, safety, hubs on project location, and at last, recycling techniques.

Biobased materials

Not all biobased material has their LCA online available. An example is a biocomposite. A growing amount of biobased and biodegradable plastics are currently.available on the market. New markets can be set up for innovative composites and plastic recycling to eliminate the plastic waste and close the plastic chain. The challenge for these synthetic materials is to reduce their dependency on fossil fuels and to be able to assure the right properties and grades for composites.

Stigmas on biobased products

Many biobased materials have incorrect stigmas: reed, flax, straw, bamboo, hemp, and sheep wool. The application of these materials is still very small, and significant upscaling will be required to increase its share in the building industry. There is enough potential for growing these raw materials on a larger scale, but it requires significant investment in production and processing capacity. It seems necessary for the government to effectively utilise and unlock the available potential (NIBE, 2019).

Contaminants

Contaminants in aluminium scrap caused by different alloys of hinges and locks, stainless steel screws, etcetera can be reduced by optimising these parts' uniformity. Furthermore, the contaminants in the form of glass, rubbers, and plastics can be reduced by dismantling them off the aluminium parts and cleaning the profiles. Requirements of how these materials are delivered must be set. Furthermore, the logistic flows between large and small quantities of aluminium scrap material must be approached differently and distinguish between pre-and postconsumer and type of material (profile, plate). These are factors that influence the price of material while registration is lacking at the moment. (Huurdeman, 2017).

Safety and hubs on project location

When little space at the project site is available, separation of materials should be made possible in an external separation facility where weather conditions do not play a factor. The number of separation facilities in the surrounding area of the project may increase the potential for recovery of materials from a demolition project (Huurdeman, 2017).

Recycling techniques

Good recycling techniques are still to be developed (Dijksma & Kamp, 2016).

§4.4.4 Summary

This paragraph will answer the question:Which foreseen bottlenecks of the circular economy in the residential sector be prevented through procurement? There are still many bottlenecks that should be overcome. However, several of the above-written bottlenecks could be tackled using a new kind of procurement method. This procurement method should be data-driven and integrate the environmental costs. Furthermore, it should enhance circular business models, the use of biobased products, and he project location to consider the ability of hubs for renovation.

4.5 Implementation of Sustainability in procurement

This paragraph will answer the following question: How can a procurement method, with the focus on the initiation phase, introduce circularity in the project? The following aspects will be discussed: the traditional procurement procedure, sustainable award criteria, and examples are given with the circular tender roadmap and the Pre- Returnable Procurement (PRP).The paragraph will close with an answer on the question in the conclusion. Currently, procurement is mainly about achieving the best price-quality ratio. However, the purchasing power can be used to increase the circularity aspects in the project as it can affect the design decisions. It could be stated that purchasing has a big influence on the initiation of circularity in the project, and the more circular projects are asked for on the market, the more advisers, contractors, and suppliers have to implement it into the design. Therefore, the project developer has an important role and can be seen as the gateway towards a circular economy (EIT Climate-KIC, 2019).

§4.5.1 Traditional procurement procedure

Tendering is described as the process where the project developer makes the agreements with the architect and contractor. Tendering exists of a few phases.The selection phase, the offer phase, and the award phase.In the traditional selection phase, the project developer will first contract the architect for a design; the contractor will be tendered to realise the elaborated design. Another selection phase contract is also possible that involves the design with arrangement services and works. Finally, there is the selection phase with the architectural competition (Volker, 2010) to select the architect. In the selection phase, the project developer decides on the selection criteria which the architect needs to submit for the offer phase. In the award phase, the winning tender's choice is based on the award criteria. These award criteria can be based on the lowest price or the most economically advantageous.

The tendering process depends on the chosen procedure: an open procedure, a non-public procedure, or a private procedure.
In the open procedure, all interested architects or firms immediately submit a tender, including a statement that meets the set suitability requirements. However, the selection criteria must meet certain conditions under which the criteria must be clearly formulated, announced in advance, and may not be changed afterward. An assessment committee will first assess the participants' suitability based on previously published requirements, and unsuitable tenders will be excluded. The committee then assesses the registrations based on pre-published criteria to identify a winner who will be awarded the contract (Architectuur Lokaal, 2016).
In the non-public procedure, interested agencies can register. A selection committee first assesses the suitability of the participants based on previously published requirements ("suitability requirements"). Unsuitable agencies will be excluded, and the remaining companies will be assessed. The best suiting parties are then selected to submit their proposal in the tender phase. In this second round, an evaluation committee assesses these registrations based on previously published criteria to identify a winner to whom the contract will be awarded (Architectuur Lokaal, 2016).
In the private procedure, a limited number of companies are invited, and the majority of these types of proceedings are not announced publicly. A committee assesses the tenders in order for the award. Project developers prefer this type of procedure to lower the bargain costs (Architectuur Lokaal, 2016).
In the non-public procedure, interested agencies can register. A selection committee first assesses the suitability of the participants on the basis of previously published requirements ("suitability requirements"). Unsuitable agencies will be excluded, and the remaining companies will be assessed. The best suiting parties are then selected to submit their proposal in the tender phase. In this second round, an evaluation committee assesses these registrations based on previously published criteria to identify a winner to whom the contract will be awarded (Architectuur Lokaal, 2016).
In the private procedure, a limited number of companies are invited, and the majority of these types of proceedings are not announced publicly. A committee assesses the tenders in order for the award. Project developers prefer this type of procedure to lower the bargain costs (Architectuur Lokaal, 2016).

§4.5.2 Sustainable award criteria

Public parties such as the national government, provinces, municipalities have experimented already with circular purchasing in various projects, but also private parties and companies should be more involved in the demand development about circular construction (copper8, 2020). Bouwend Nederland (2020) analysed the inclusion of the environmental requirements and their corresponding weighting factors in open procurement in the building industry in the Netherlands. They found that a growing amount of procurements have included sustainability as an award criterion (17.9 %) with as main environmental requirement the CO_2-Performance scale ("CO_2-prestatieladder"),and sustainable execution of the process. There is a direct correlation between the result and the way requirements of the tender have been formulated and weighted: When the minimum price has the highest weighting factor, the chance arises that contractors will put their focus on price instead of achieving better requirements as can be achieved when including a reference project. The awarding of the contract, however, depends on the chosen procurement method. There are mainly two methods used: The lowest price and a value-based procurement.

The lowest price based procurement is the traditional form where only the price counts. A tender that does not meet the minimum qualifications will be discarded, and a tender that exceeds the minimum qualifications will not be awarded extra. If the minimum qualifications cannot be specified precisely, there is a risk that the 'lowest price' criterion will lead to an outcome that does not meet the minimum qualifications. To prevent this, the specifications must be clear enough that no differences in interpretation can arise afterward, leading to additional work. Next to price also the consideration of costs associated to the entire life cycle of a product. In this way, contracting authorities can also consider sustainability in the tendering procedure (Pianoo, 2020). Limpers (2020) research shows the advantages of a value-based procurement called Economically Most Advantageous Tender (EMAT). In this procurement type, other criteria, in addition to price, can be taken into account such as sustainability measures. There is no restriction for the number and type of award sub-criteria as long as they relate to the assignment. The criteria must be objective, transparent, and proportional, and these criteria must also be formulated clearly in such a way that all parties can interpret these criteria in the same way. The assessment of the parties can be done in different ways. However, according to Pianoo (2016), it is recommended not to use a relative method, but instead, the score should be the result of the assessment categories, which can strongly influence the differences between the outcome. Limpers (2020) has researched the inclusion of environmental requirements in public procurement strategies for his master thesis to analyse the main reasons for the lack of sustainability in the execution of projects. Limpers divided the problems into two categories: on organisation level and the procurement process itself. Typical problems that can occur when implementing circularity in the organisation of the procurement are the lack of a responsible designated and greenwashing. In the process are the following mainproblems: limited feedback and limited environmental inclusion, resulting in a lack of knowledge. The result is a list of advice for procurement to go well. They will be summed up here:

- The project initiation should include a textual reference to clarify environmental ambitions and goals.
- The selection criteria should request sustainable certifications.
- The award criteria should have open, self-contained and, equally weighted environmental requirements.
- Contract performance clauses should contain a minimum to acquire environmental goals.
- The sub-award criteria should be chosen depending on the invitation to bid.
- The assessment of the bid on the award criteria should give feedback with both positive and negative aspects next to the given scores. The feedback needs to be well documented to learn from.

§4.5.3 Circular procurement roadmap

The Municipality of Amsterdam has initiated a roadmap to include sustainability in tenders to set binding conditions for construction in exchange for handing over land to the developer (EIT Climate-KIC, 2019). The roadmap focuses on materials, adaptivity, water, energy, and biodiversity.The tenderer is asked to describe its sustainable vision in the design of the whole building and the building's addition means for the location. The tender is divided into a few phases. In the first phase, the tenderer needs to submit a sustainability concept that explains how the tenderer will realise the sustainable ambition. On the material level, this means that the MPG value is asked. For adaptability, a few questions will be asked on the building construction's flexibility (unit level, interior level, installations, and building level of the casco).A certain threshold value is considered (below 0,8 € /m² / year.) The tenderer with the best MPG-score receives the maximum point for this part. In the second round, the energy performances are asked from the selected parties. Collecting renewable energy is positive for the building's energy performance but is usually negative for the MPG score. The BENG results are in this phase also asked. Applications that do not meet the Amsterdam BENG standards, which are more severe than on the national level, will be excluded from further participation in the selection procedure. However, the MPG score may not be worse than submitted in the pre-selection(Gemeente Amsterdam, 2020).

In the final selection round, the selected tenderers should provide a brief description (maximum 1 A4) of the way in which adaptivity and flexibility are given a place in the development. Also, the tenderer must complete and submit the MAT 8 tool from BREEAM. The registration with the highest MAT8 score will receive the maximum number of points. However, BREEAM and MAT8 are not providing sufficient insight into the circularity aspects. A different and more expanded method should be used. It must be noted that the preliminary design and definitive design will not be identical to the submitted sketch design; the calculations' results may turn out different in later phases than at the phase of the tender. However, the tenderer is obliged to score at least the same as the values submitted before.

Amsterdam's municipality is not the only governmental party in the Netherlands that is active in implementing circularity into the procurement. The Green Deal Circulair Procurement (GDCI Green Deal circulair inkopen in Dutch)is an initiative where public and private parties work together to bundle their knowledge and boost the circular economy on procurement policy. Theinvolved parties are: MVO Nederland, NEVI, de Rijksoverheid, Duurzame Leverancier, PIANOo, Kirkman Company and Circle Economy D (Pianoo, 2020).

§4.5.4 Pre- Returnable Procurement (PRP)

The municipality of Wageningen uses the tool Pre- Returnable Procurement (PRP) matrix developed by Rendemint (Hooijmeijer-Versteeg, 2016). This is an online tool that makes circular tendering more explicit by setting the requirements and criteria that should lead to a more circular result on the material level. It differs from the roadmap of Amsterdam's municipality on several topics: First of all, the tool is also meant for the tenderer as it should submit all the necessary information and documents of the used products and materials. This is also needed for verification. Secondly, the product's submitted data will be saved in the database and can therefore also be used by the tenderer to review and compare its own product to others. Above this, the method of awarding the assessment is also different. With PRP, the tenderer fills in all known the information, and the tool will generate a relative score based on all tenderers on the material and raw material passports. Furthermore, the tool uses a scoring based on the percentages and kg of recycling, downcycling, and incineration (Vink, 2020). Awarding should thus be based on the most suitable partner that adds to the sustainability vision.

§4.5.5 Summary

The following question will be answered with a summary of the above-written text. How can a procurement method, with the focus on the initiation phase, introduce circularity in the project? Procurement has a big influence on the initiation of circularity in the project. If the purchaser's aims are not clear right from the start of the project, the tenderers and parties involved will not focus on these aspects. The traditional tender process contains a few phases. The selection phase, the offer phase, and the award phase. In the traditional selection phase, the project developer will first contract the architect for a design, and whereafter the contractor will be tendered to realise the elaborated design.

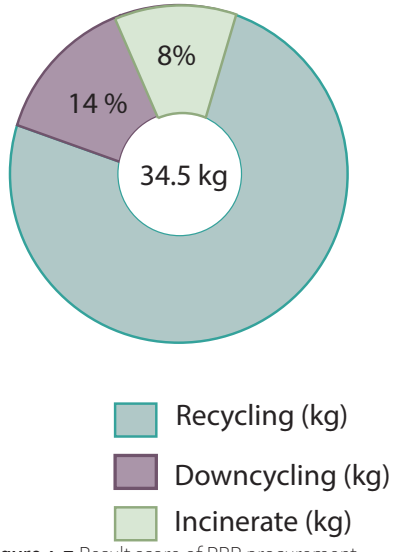


Figure 4.7:Result score of PRP procurement. Based on: (Hooijmeijer-Versteeg, 2016).

There are mainly three tendering processes: an open procedure, a non-public procedure, and a private procedure. For architectural projects, the project developer prefers private selection to lower the bargain costs. The awarding of the contract, however, depends on the chosen procurement method. There are mainly two methods used: The lowest price and a value-based procurement. Furthermore, there is a direct correlation between the result, and the way requirements of the tender have been formulated and weighted have been found: When the minimum price has the highest weighting factor, the chance arises that contractors will put their focus on price instead of achieving better requirements. Bouwend Nederland (2020) analysed the inclusion of sustainability requirements and their corresponding weighting factors in open procurement in the building and construction industry and found that a growing amount of procurements have included sustainability as an award criterion. However, these sustainability aspects are mainly steered by energy-efficiency and the aim to reduce the consumption of energy during the use of the building, rather than going fully circular. Public parties such as the national government, provinces, municipalities have already experimented with circular purchasing in various projects. But private parties are rarely experts on circular building.This may lead to a lack of clear requirements to include in the tender. To counteract this, municipalities try to create a framework that can help project developers set circular requirements. Amsterdam's municipality is developing binding conditions that focus on circularity for construction in exchange for handing over land to the developer (EIT Climate-KIC, 2019). A roadmap will, in this way, help to decide on which circularity aspects should be focused. However, as this is mainly based on construction, the roadmap is not precise enough for buildings to really make a difference. The Municipality of Wageningen has also experimented with a form of procurement where the focus is set on the materiality of the project's products. This method allows a more open dialogue between purchasers, contractors and material suppliers. The suppliers need to fill in all the details of their product, which gives them more responsibility. It is thus a form of data-driven procurement where the selection of the winner is based on the most suitable partner that adds to the sustainability vision.

4.6 Summary

In last five paragraphs, information has been gathered to answer this question, and this paragraph summarises the main foundings.

The project developers: social housing organisations and local owner associations own a significant part of the residential building stock. Some social housing organisations have already gained experience in renovating their stock to stop the existing housing stock from heating with natural gas and the increase of energy performance in buildings. However, both groups lack the in-house knowledge to find optimal design solutions that combine sustainability with affordability. Therefore, the architect and engineers' expertise will become more important to implement circularity into the projects. The role of the contractor will change by integrating the chance to decouple the link to the mining of new materials with its economic growth. Rent, buy-back, or the lease of facades can assure that the contractor can retrieve the product back after the end-of-life. Most of these circular business models will imply a long-term connection with the product. Moreover, insight into chain partners' products will become increasingly important and will lead to data-driven procurement. The role of the supplier will grow and change in several aspects. Reverse logistics will become part of the job, leading to improved technical design due to better insight into its life span. As producers are the experts on their (circular) field and products, collaboration and interdisciplinary thinking will become more important to design circular buildings.

The second paragraph answers the following question: What are the ambitions and incentives of the Netherlands concerning a circular economy in the built environment that could be stimulated through procurement? There is a growing amount for the need for houses in the Netherlands. However, in the last few years, the ambition to build them has not been reached because of the policy to reduce nitrogen. Nitrogen during the construction phase is governing above the user phase. A few ways to tackle this is to build with light-weighted, modular prefab elements. In this way, fewer heavy construction units need to reach the building site. The circular economy can create many opportunities for the Netherlands. One of them is the creation of new jobs, which tenders can stimulate by the weighting factor of the scoring.Examples are local companies' stimulation, start-ups, local materials and technologies, reverse logistics, biobased products and nature-based solutions.

The third paragraph will answer the following question: Which methods and strategies can lead to accomplishing circularity goals for a building project applied through procurement? There are mainly three ways in which a building's performance level can be demanded. These three ways are either with legislation, economic incentives, or certificates. There are certificates and labels such as Breeam, LEED, and Well. Several labels are usually meant for high-end projects, but the project developer can also prove the building project's quality and circularity performance. The building market effectively avoids more expensive solutions when no sufficient added value is gained with the alternative. Therefore, the third way to demand sustainable requests in building projects is with economic incentives such as a green declaration that can offer a discount on the mortgage if it can be proved that the building project will meet the set requirements.

How are in the traditional procurement method, focusing on the initiation phase, circularity goals accomplished in projects? Procurement has a big influence on the initiation of circularity in the project. The more circular projects are asked on the market, the more advisers, contractors and suppliers have to implement them into their design proposal. A direct correlation between the result and the way the tender requirements have been formulated and weighted has been found. If the project developers aim is not clear right from the start of the project, the tenderers and parties involved will not focus on these circularity aspects.

The Netherlands has many incentives and has the ambition to become fully circular in 2050, and several governmental parties have already gained experience with applying sustainable factors into the tender process. A growing number of projects are using tools such as the CO_2- prestatieladder. However, these projects are just focussing on energy-efficiency and the aim to reduce energy consumption during the use of the building, rather than going fully circular. Amsterdam's municipality is developing a circularity roadmap to demand circularity aspects of the projects built on its land. A roadmap will help decide which circularity aspects should be implemented for an arbitrary project area in Amsterdam. However, the roadmap is not yet precise enough to make a difference. Furthermore, the municipality of Wageningen has also experimented with a form of procurement. The focus is set on the materiality and thus recyclability of the project's products. The suppliers need to fill in all the details of their product, which gives them more responsibility. Thus, it is a form of data-driven procurement, where the winner's selection is based on the most suitable partner that adds to the sustainability vision. This method allows already a more open dialogue between purchasers, contractors and material suppliers.

4.7 Summary of the literature review

This paragraph gives an overview of the literature relevant to constructing a procurement method to stimulate circularity. Figure 4.8 shows the found circular economy's incentives, the bottlenecks, and the recommendations in the literature and are categorised in three fields of study: Material, legislation/social-economic, and building technique. The following pages explain the different icons shown.

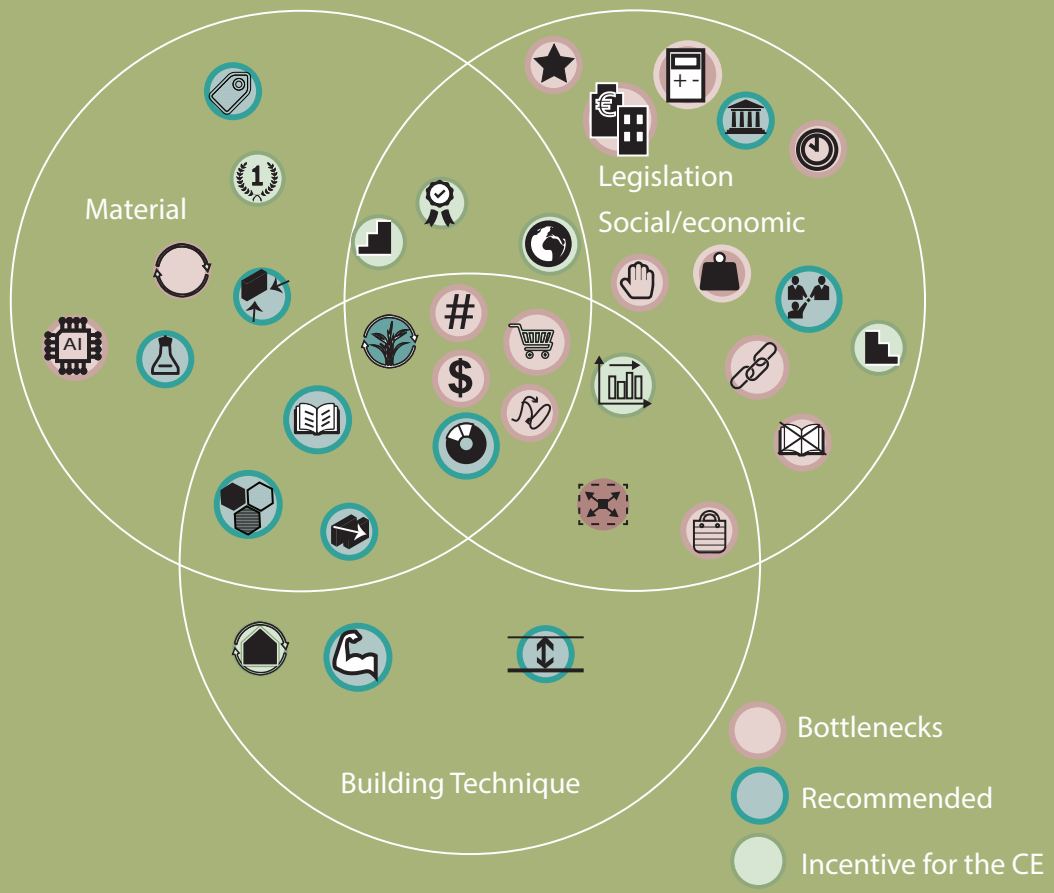


Figure 4.8: Circular economy's incentives, the bottlenecks,and recommendations on procurement. Own figure

§4.7.1 Incentives of the circular economy on which a procurement method can respond

The demand for raw material has grown enormously in all sectors, and this number will even be more prominent due to the global population growth. This growing demand will lead to an increase in environmental pressure by the exhaustion of the natural capital. The Netherlands' dependency on other countries for raw material supply can lead to more geopolitical tensions and affect supply prices as the Netherlands strives for a decoupling of resource usage. The government works with other countries in the European Union and the United Nations as much as possible. The materials should be chosen based on origin. (government.nl)

Registration and certification are needed to keep materials inside the EU for a closed-loop and encourage recycling and cascading (biobased) material. Certifications can also be used as proof to show that the project has met the requirements for legislation or economic benefit.

Methods such as the MPG could play an important role in the future regarding a fair price system. However, more development for a good working system concerning LCA, MPG, NMD has to be worked on. (legislation/national/tenders). The MPG should also be used in the procurement method to also take the environmental impact of the project into account instead of tendering on the lowest price only (Dijksma & Kamp, 2016).

The Netherlands counted over 7.266.295 dwellings in the year 2012. 29% consists of multi-family houses. As most of the buildings before 1970 need to be better insulated and all buildings from before 1990 require large interventions, the facade is an essential part where circular strategies can be integrated during renovation.

Cascading of these biobased materials is furthermore also very important and should be stimulated.

The Netherlands has a leading position in biobased and nature-based solutions (Dijksma & Kamp, 2016). The government wants to keep this leading role and stimulate biodegradable applications such as biofuels and initiate them within the national and European product policy. However, to better develop these biobased materials, the market should become more stable to attract more investments. More biobased alternatives of timber should be stimulated with procurement such as reed, flax, hemp, bamboo, and straw.

The housing market in the Netherlands is tight due to factors such as population growth, migration to urban regions, an increase in one-person households, low-interest rates and increased incomes, while the construction of housing has lagged far behind because of the last crisis (Ollongren, Nationale woonagenda . To reduce nitrogen pollution for building projects, prefabricated, lightweight building envelope elements allow for less polluting machines on the building site, resulting in easier authorisation for the project.

§4.7.2 Bottlenecks of the circular economy on which a procurement method can respond

Circular procurement will be more time-consuming. It will require to create a planning process from the beginning, it requires the necessary investigations and engaging all the partners (architects, constructors,suppliers) .However it does not neccessarily have to be more expensive.Altough the design costs will be higher, it would not outweight budget of the whole project. (EIT Climate-KIC, 2019).

When little space at the project site is available, separation of materials should be made possible in an external separation facility where weather conditions do not play a factor. The number of separation facilities such as hubs in the surrounding area of the project may increase the potential for recovery of materials from a demolition project (Huurdeman, 2017).

The development of detection and inspection techniques is important to stimulate the use of secondary products and materials. Furthermore,there is currently not enough information about the material stream after usage. Techniques artificial intelligence could help to gain insight in the material flow between sectors.- Demand mono-materials.

Small, innovative start-ups experience difficulties participating in warranty and guarantee agreements. For this reason, it is more plausible for companies with more capital to succeed unless more aid, guidance and/or subsidy will need to be pumped in start-ups, but procurement could stimulate the choice of products from start-ups.

Public parties such as the national government, provinces, and municipalities have experimented with circular purchasing in various projects, but private parties and companies should be more involved in the demand development regarding circular construction (copper8, 2020). However, they often lack knowledge and experience.

The procurement of a circular building is more complex and lengthy to an existing product or service (EIT Climate-KIC, 2019). In the building industry, procurement is also about design, contracting, and, in some cases, construction management. Furthermore, the life cycle of a building also includes the procurement of maintenance and demolition.

Good recycling techniques are still to be developed (Dijksma & Kamp, 2016). Therefore, design for disassembly and choices for mono-materials are even more important.

According to Yuang, Bi, & Yuichi (2006) the precise definition of the circular economy is not yet commonly accepted and there are as many definitions for the concept of circular economy as there are parties defining it.Therefore, a procurements should be based on the priciple of the circuar economy and offer a common framework to prevent greenwashing.

The knowledge and experience gained in the traditional way of construction lead to lower prices. This promotes the preference of traditional and thus linear choices.

The project developer has an important role and can be seen as the gateway towards a circular economy.However, project developers lack the in-house knowledge to provide the parties of a clear aim and guidance to find optimal design solutions that combine sustainability with affordability.

The MPG should also be used in the procurement method to take the environmental impact of the project into account instead of tendering on the lowest price only (Dijksma & Kamp, 2016).

Many tenders still choose price as the highest weighting factor. The chance arises that contractors will focus on price instead of achieving better requirements. Bouwend Nederland (2020). However, to create a circular project, awarding should be based on the most suitable partner that adds to the sustainability vision.

There is an alignment problem in the product chain. Parties should streamline the materials together. This starts with the mining of raw material to product design and ending with the recovery of the used materials. Currently, the end-of-life scenario is not thought out thoroughly enough (Dijksma & Kamp, 2016). Reverse logistics, where the supply chain moves from the end-use, is still expensive but can be stimulated through procurement.

Bankers and investors have a huge role in financing circular business models. They need to think of new calculation models that calculate the right chances and risks for as-a-service products. Furthermore, they have to think about different strategies to help finance circular start-ups (MVO Nederland, 2016). Choosing start-ups and for companies that apply circular strategies could help.

The calculation method for expressing Co2 production should be changed for a fair biobased comparison. According to NIBE (2019). More weight should be on the production process and less on possible recycling, reuse, and energy recovery. At the moment, all life-phases are combined in one number but dividing the result per life phase would give a clearer distinction. The proposed method should show the absorption of CO_2 by biobased products as a harmful emission in the production phase and positive in the end-of-life phase. On a total 'cradle-to-grave' LCA, it would not result in a different outcome, but the underlying effects would be visible in the LCA's distinction of life phases.

Many biobased materials have incorrect stigmas over the whole market: reed, flax, straw, bamboo, hemp, and sheep wool.

§4.7.3

Recommendations of the circular economy on which a procurement method should respond.

When these requirements of the functions of the facades are understand and met, there is less chance that endogenous physical obsolescence will cause earlier than intended demolishment. Applying suitable materials, in line with the environmental conditions, are thus of importance to maximise the life of the façade.

Circular ambitions in the procurement should be set together with the whole network, and broadcasted to the outside world as a control mechanism. This strategy already proved promising results.By sharing a common goal in procurement instead of setting limits and restrictions to the supply chain, improvement in chain network connections can be achieved (Circl, 2019).

Public authorities should take initiative to include sustainability in tenders to set binding conditions for construction in exchange for handing over land to the developer. (EIT Climate-KIC, 2019).

Making use of donor material in the area should be enhanced to minimise transportation and stimulate the use of secondary materials. This could be achieved by the use of a harvest map or tag systems.

For easy transportation, the size of the elements should be not too big, furthermore, qualitatively stable, lightweight and modular elements can also make this process easier and faster.

The facade should be self-carrying, meaning apart from its dead load, it should not be load bearing. The skeletal frame structure and loadbearing internal traverse walls offer thus most flexibility.

The building envelope systems should allow for upgradability to deal with physical ageing, performance requirements, user satisfaction and style obsolescence.

Procurement strategies should further develop into data-driven procurement to achieve better transarency as control mechanism. Data should be retrieved from all parties involved. Examples of this data are: pollution rates of the area and quality control of the suppliers. This will help to make a more responsible practice possible where society's future is respected (Circl, 2019).

The guidelines for building products should be used to enhance demount ability and easy accessibility, and the choice of materialsto keep them usable for as long as possible.

The location of the building influences the material durability of the facade by the salinity in the air, sun orientation, the distance and intensity of roads and traffic. Applying suitable materials, in line with the environmental conditions, are thus of importance to maximise the life of the façade.

When the facade is designed for adaptability, through for instance by use of modular design, or through convertible assets, the façade can easily be upgraded. In this way, demolition or replacement of an existing façade may be prevented.

Chapter 5

The circular procurement tool

§5.1 Requirements of the tool
§5.2 Concept of the circular procurement tool
§5.3 Construction of the tool
§5.4 The use of the tool
§5.5 Concept evaluation

From the previous chapters, it becomes apparent that many new houses will be built or renovated in the coming years, a systematic approach to implementing circular economy strategies could help achieve higher success potential. Purchasing power can be utilised as an accelerator of the circular economy. This chapter will introduce a methodology of a procurement method where the municipality can take the first step to introduce its circular ambition for an arbitrary project on its location. Paragraph 5.1 will introduce the concept of the circular procurement tool. Paragraph 5.2 explains the requirements of the tool. Paragraph 5.3 will show how the involved parties can use the tool and what the results generate as output. The chapter will close with a summary of the chapter in paragraph 5.4. The relation of this chapter to the whole thesis can is shown in figure 5.1.

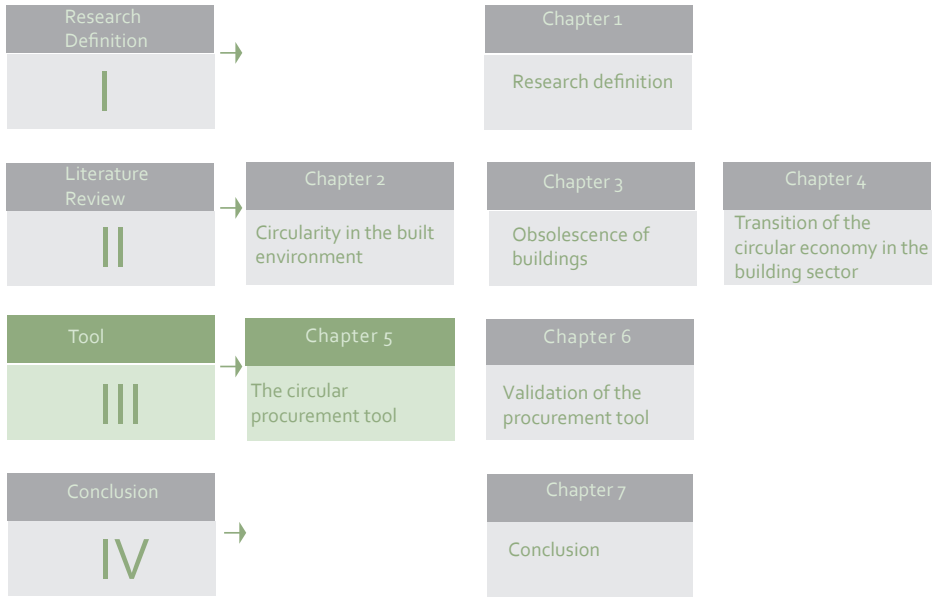


Figure 5.1: Place of chapter 5 in the thesis. Source: Own figure.

5.1 Requirements of the tool

This paragraph is giving the requirements of the tool and what the tool should avoid. These tool's requirements are mainly based on the literature study described in chapter four that covered the existing circularity tools and tender methods. This literature research is complemented with interviews with field- experts within the building industry.

The following page contains a summation of the tool's primary requirements and can be seen as the circular procurement tool's design brief. In comparison, the column on this page shows the rules what the tool must avoid.

What the tool should avoid:

- Reveal secret information about the product or company.
- Block information
- Substitute other tools
- Some tools that have been described in the literature use weighting factors that are determined as arbitrary or not understandably (Deckers, 2020).The proposed new tool can only be of value if it is transparent, utilises a straightforward way of assessing, and can cover the whole range of the circular economy. It should avoid formulating one unclear score.

Brief of the tool: what the tool should do

- The tool should avoid utilising multiple-choice options as it may obstruct innovative answers. Right now, certifications such as BREEAM are drivers for sustainability on the client-side. However these certifications leads to conventional solutions with a given set of rules rather than encouraging (architectural) creativity.
- Next to this, the tool should avoid reinventing the wheel so that double work can be avoided. It, therefore, should incorporate existing tools results such as the MPG and not replace it.
- To prevent the tool from outdating, it should be updatable where irrelevant topics can be deleted and replaced by new, more relevant ones
- The tool should be flexible enough to cope with multiple levels of information from global to precise, as not all information is known beforehand, while also precise information is required to avoid that the tool promotes greenwashing
- Enhance collaboration
- Allow parties to take an active part in the circular ambition
- The tool should give and enhance overview for all parties All parties should gain insight/understanding of their choices
- Divide responsibility to parties- clear agreements
- Monitoring should be possible to give an overview and keep track
- Verification at the end of the process should be possible.
- Prevent greenwashing
- Stimulation of innovation with open questions.
- Incorporate answers to other tools to stay relevant.
- Flexible answer levels. Not everything is known at the start.
- Divide circular economy into aspects and let the initiator choose the importance.
- Divide questions based on the required knowledge of the people.
- Allow change during the design process
- An absolute score should be the output for the tender to compare systems/ parties
- The assessment method for building products should be based on the principle of the circular economy
- The contract should contain a minimum to acquire environmental goals
- The contract should also contain ambitions higher than the set goal environmental goals Realistic project ambitions
- Data driven procurement for transparency.

5.2 Concept of the circular procurement tool

One of the circular economy problems is that there are as many definitions for the concept of the circular economy as parties are defining it. This makes "circularity" susceptible to greenwashing. Therefore, a circular procurement method should be based on the principle of the circular economy and offer a clear framework with common rules for every party using it.

The building market works effective and avoids more expensive solutions when no sufficient added value is gained with the alternative. As the knowledge and experience gained in the traditional way of construction lead to lower prices, this promotes the preference of traditional and thus linear choices (NIBE, 2019). To counteract this, the government could, by legislation, oblige projects to be more sustainable, for instance, by requiring a more severe MPG result or by providing economic incentives for the project developer when these results can be proved in the project.

The project developer, in particular, has an important role as it can initiate sustainable requirements for the project. However, project developers lack the in-house knowledge and experience to demand circular requirements. This results in steering on the building energy performance to reduce energy consumption during the use of the building rather than going fully circular (EIT Climate-KIC, 2019).

Circular procurement will require a good planning process from the start of the procurement. As the awarding should be based on the most suitable partners that adds to the project's sustainability vision, it requires the necessary investigations and engagement of all the parties such as architects, constructors, and suppliers already in an early phase of the procurement.

Data-driven procurement will help to achieve transparency. Retrieving data from all involved parties is also essential as most of the products' knowledge is at the supplier and contractor.

The circular ambitions in the procurement should be set together with the whole chain. These ambitions could be broadcasted to the outside world as a control mechanism. By sharing a common goal in procurement instead of setting limits and restrictions on the supply chain, the parties' connection can be improved (Circl, 2019). Furthermore, cooperation between these parties will remain important during the whole procurement as the building's design may change from the start of the contract until completion. It is recommended to have cooperation meetings and to monitor the circular economy issues.

The circular procurement should respond to the scheme of figure 4.8 to implement the circular economy's incentives, bottlenecks, and recommendations to stimulate the transition towards the circular economy. Although this probably implies higher design costs, it will not outweigh the budget of the whole project. It takes into account the life cycle of a building, including costs of maintenance and demolition (EIT Climate-KIC, 2019).

Circular procurement will cost more time as it requires a lot more planning in the process and a precise sustainable aim from the beginning. (EIT Climate-KIC, 2019). Developing a tool that can help public authorities such as the municipality set circular binding conditions for the project in exchange to hand over land to the project developer. Through these binding conditions, the municipality can demand the project developer to include the tender's specific sustainability requirements in exchange for handing over land for the project.

As the project developer lacks the knowledge and experience in circular tendering, the tool should help make the practical implications of the circular ambitions of the project developer and municipality explicit. The systematic approach of the tool can help make this process less time-consuming. The tool should guide the project developer with the selection procedure of parties that share or add to the project's sustainability vision. Furthermore, the tool's concept is to categorise and assess the individual benefits of the circular measures in the chosen products, based on the phases and parties.

By utilising this tool, it should become possible to compare and select a facade system for the project. Furthermore, it should keep track of the process by monitoring the set goals during the projcurement to make necessary adjustments. Monitoring can guide discussions in cooperation meetings. This is needed because usually, the design of the project will evolve even after the contract phase. Therefore, the tool needs to allow creativity in the process at the start of the project (design brief) and high accuracy at the end (where the technical drawings and execution plan are required).

Moreover, at the end of the project, the result should be evaluated with set goals of the municipality (governmental authorities) and project developer.

The aim of using the circular procurement tool's is shown in figure 5.2 which shows that the tool should be used by the involved parties and throughout the whole procurement process.

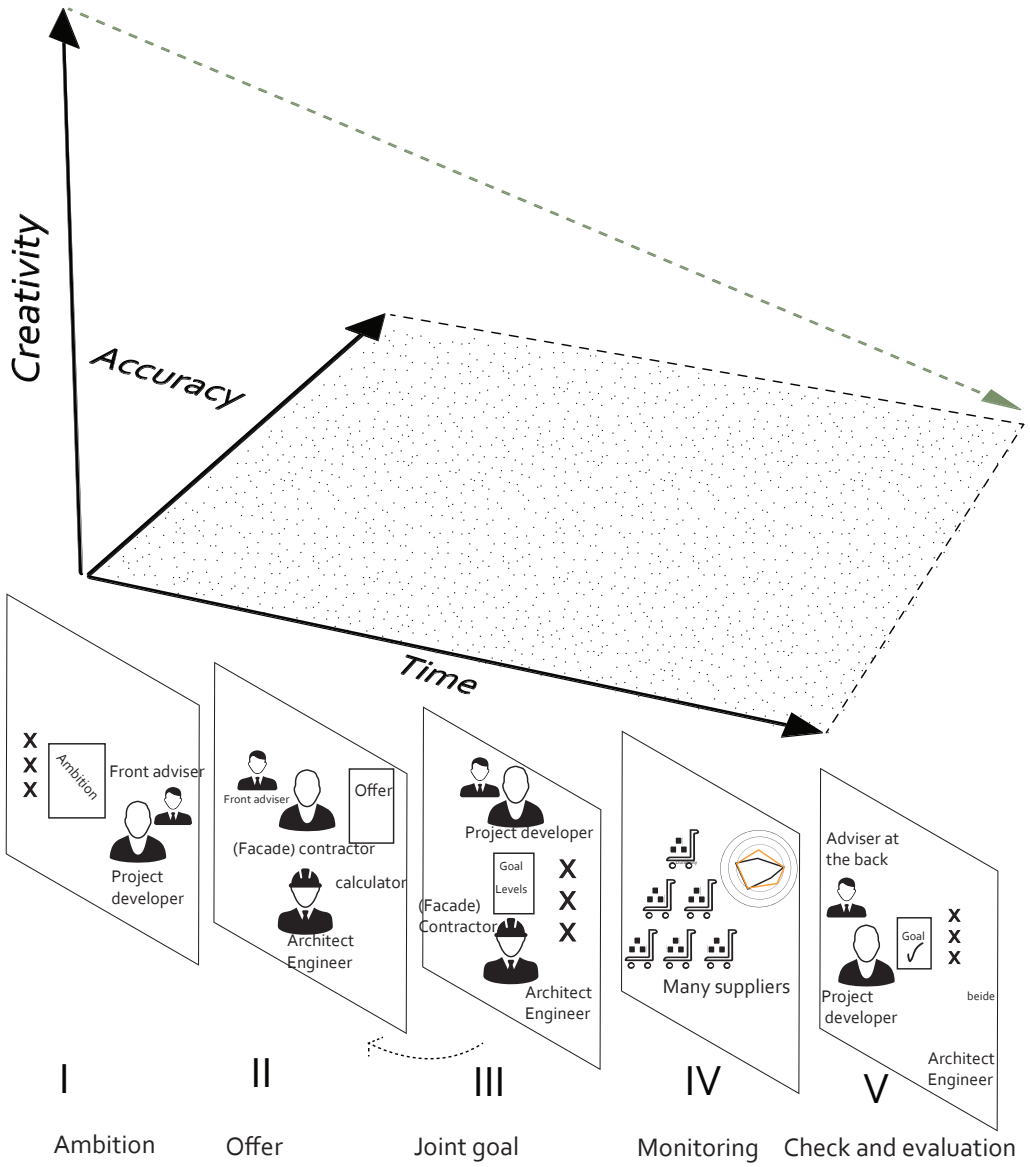


Figure 5.2: Concept of the circular procurement tool throughout the project Source: (Own figure.)

5.3 Construction of the tool

This previous paragraphs have shown the requirements of the tool and the concept. This paragraph will clarify the construction of the tool. A link between between the tool and the literature research will be made. and the paragraph will show how the tool is constructed based on the literature and which rules will be used. The rules on which the procurement tool is constructed will be explained here.

§5.3.1 The principle of the tool

The circular procurement tool will be based on the three main themes of the circular economy principle described . in paragraph "2.1 *Circularity defined* " (figure 5.3).

- Reduce the use of raw materials
- Prevention of waste materials
- Pressure release on the natural capital

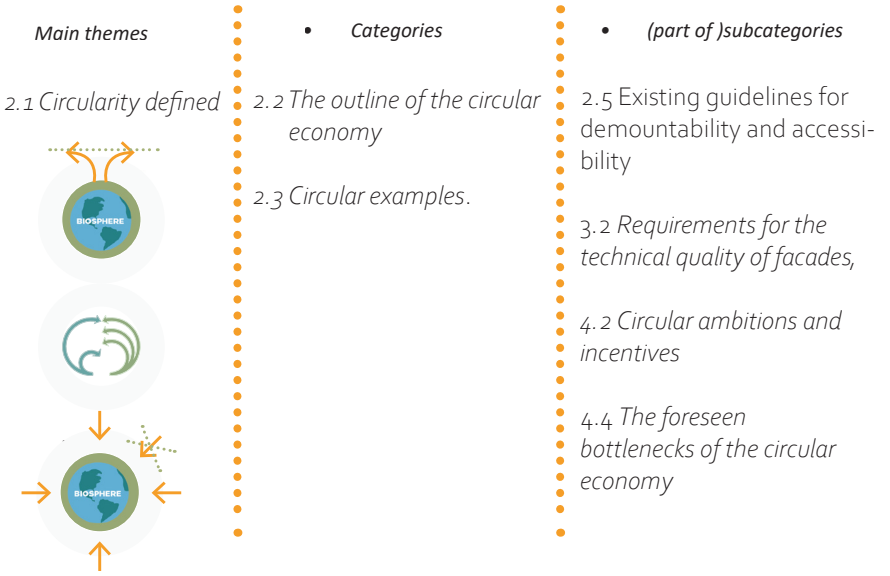


Figure 5.3: Hierarchy of the tool and the relation to the paragraphs of the literature.Source :(Own figure)

§5.3.2 Introducing product levels

Furthermore,based on paragraph 2.4 the layer of the facade can again be subdivided into levels as well as building products. For this thesis the following levels will be used: Element level, product level,and system level (figure 5.4).

- *The element level*
  Defined as material that has been processed into its final shape and finished (figure 5.5).
- *The product level*
  The product is a combination of elements and connections.
- *The system level*
  The system includes all products and connections between the products to form the facade.

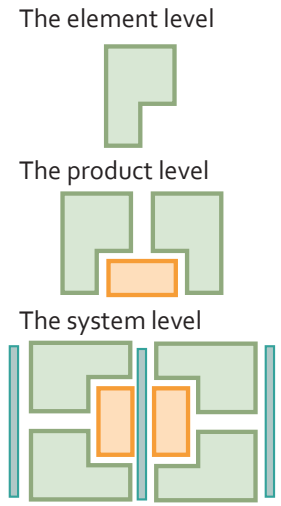


Figure 5.4:Element, product and system level (Own figure)

§5.3.3 Scoring in the tool

The tool works with weighting factors based on the principles of the' Ambitieweb' (DuurzaamGWW, n.d.) and the 'omgevingswijzer'. These methods are already known in the non-residential construction sector. However, for the method constructed in this thesis, a new level is introduced: Level 0. This level is relevant for the project developer if a subcategory is not applicable or does not need to be covered.

Level 0: Not applicable

Level 1: Insight and a minimal level of improvement

Level 2: Measurable / Verifiable objectives and achievement of relevant reduction

Level 3: Maximum effort and achievable

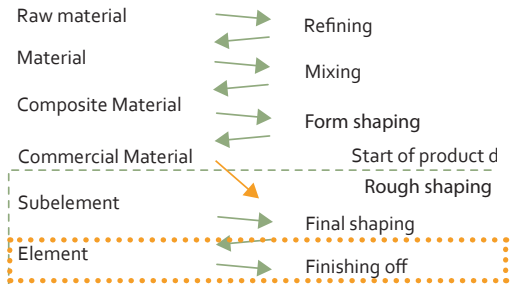


Figure 5.5:Definition of an element based on: (Eekhout, 2006)

5.4 The use of the tool

The concept of the tool is built in excel 2016. To accommodate the different parties and project phases in the tool(table 5.1), every phase and party has its tab as they require different levels of accuracy. The tabs are ranked in the same order as the project phases project (figure 6.1.1).

The Municipality utilises "0.1 Requirements (municipality)" to decide which of the three categories should be focused on by determining the weighting factors of the main categories based on levels one to three. The levels will correspond to a certain amount of points that need to be achieved by the relevant subcategories.

The second tab is to set the project's ambition by deciding the weighting factors per category in more detail. The total amount of points per the main category always needs to fulfil the Municipality's minimum score. In contrast to the Municipality, the project developer can also assign a category the level '0' in the case that this category would not be relevant for the project.

The third tab (2.1) describes the tender entry of the designer. In case of multiple design parties (building physics engineer, architect, etc.) the tab can be subdivided in a section 2.1A, 2.1B, etcetera. All parties should still fill in the same question separately. When the (façade) contractor is chosen, the tab "Titel tab" becomes available as a dedicated tab for the said contractor.

The Execution agreement, where the parties agree on the project's circular goals and sign, is phase III of the scheme and corresponds with tab. "3.0 Execution agreement".
The following tabs are dedicated to the excecution of the set goals. The product supplier utilises tab "4.1 A, execution of 1 product". The suppliers should only fill in 1 product per tab to analyse their product (4.1A...4.1Z).

Tab 5.1 is to be filled in by the (façade) contractor or the party that assembles all components.

A Dashboard function will be shown in tab six and used as an overview of the project and for discussing purposes during meetings.

Tab	Function	Party that has to fill in the tab
0.1	Requirements	Municipality
1.0	Ambition	Project developer
2.1	Entry Designer	Architect/ Engineer
2.2	Entry(Facade) contractor	The contractor's entry for the tendering
3	Execution Agreement	All parties together
4.1A	Execution of 1 product	Supplier of product 'A'
4.1B	Execution of 1 product	Supplier of product 'B' etc.
5.1	Execution of the whole system	The facade contractor/builder that composes everything together

Table 5.1: subdivision of the tool in excel tabs.Source: (Own Table).

§5.4.1 The municipality

The tool (figure 5.6) allows the municipality to decide on the importance of the three main themes and associated categories. It is based on the literature of the circular economy discussed in the literature review. The main theme: "Reduce the use of raw materials," covers the finite stock and balance of renewable material that should be controlled to preserve materials that belong to the natural capital. The categories that are related to this main theme are either (partly) eliminating the input of raw materials or reducing it by using the materials in a smart and responsible way that replacement becomes unnecessary. The following categories belong to this first Main theme

- Biobased materials
- Durability- relation to 'n'- life
- The input of raw materials
- Secondary materials
- Repair , remanuracturing & extension of life

The theme "prevention of waste materials" is all about the ability to separate material a the end of its use, whereby material recovery of products and materials is possible. Biological nutrients can return to the soil and enable new plants to grow after being collected and manufactured into new organic materials. The following categories belong to this main theme as they are methods that help to prevent waste of materials:

- Accessibility
- Adaptability
- Closing material cycles
- Demount ability
- Materials for recycling
- Standardisation
- Mono-material separation
- Registration/quality control-Stakeholder involvement

The third main category, "lower the natural capital impact, " covers the release of natural capital aspects such as the geology, soil, air, and water due to the production of the building products. The following categories belong to this main theme:

- Contribution to the biosphere
- Energy generation/storage/exported
- Reduction of Greenhouse gas
- Use of freshwater
- Waste disposed

Furthermore, it is also possible to add categories that fall into social economics. An example is the addition of job facilities which is the case in the case-study Reigersbos. Social economics can be based on the Doughnut economics theory of Kate Raworth (Whalen, 2013).

The functionality of the tool for the municipality

The first step is to decide on the level of the three main categories. The municipality should, together with its front adviser, think about the desired ambition of the project. Preferably the ambition is in line with the context of the project. For example, is the project to be realised in a high-quality nature reserve? Is there a lot of resistance from residents? Is there any major safety or environmental risks in that area? One of the categories should have

Ambitions Main Themes		
Main themes	**Fill in***	**Mean points**
Reduce the input of raw materials	2	8
Streaming of the material output	3	22
Lower the natural capital impact (other than materials)	1	4

Ambitions Categories per Categories			
Main Themes	**Categories**	**Fill in**	**Mean Points**
Reduce the input of raw materials	Biobased materials	3	
	Durability -relation to 'n'-life		1
	Input of raw materials	2	
	Secondary materials		1
	Repair, remanuracturing & extension of life		1
Total Points - Reduce the Input of Raw Materials		8	
Streaming of the material output	Accessibility	3	
	Adaptability	3	
	Closing material circles		2
	Demountability	3	
	Materials for recycling	2	
	Standardisation	2	
	Monomaterial separation		2
	Registration/quality control	3	
	Stakeholder involvement		2
Total Points - Streaming of the Material Output		22	
Lower the natural capital impact (other than materials)	Contribution to the biosphere		0.5
	Energy generation/storage/exported		0.5
	Reduction of Greenhouse gas	3	
	Use of fresh water		0.5
	Waste disposed		0.5
Total Points - Lower the Natural Capital Impact		5	
	Stimulate the local economy	3	0

Figure 5.6: Ambitions of the municipality. The main themes and categories. (Own figure)

The main focus and classified with 'level three, maximum achievable'. The other two main categories may also be classified with level one or two. Too ambitious levels for every category endangers the feasibility of the tender (Interview with Dominique Vosmaer). It is possible that specific categories need a higher ambition level than the overall main theme. Therefore It is possible to revise these single categories and adjust the level upwards or downwards. This could be when the objective of the organisation focuses on a specific ambition, for example, a project where local jobs are created in a long and big scale project or a project where biobased materials are preferred in the area. The following formula describes the total amount of points required: The level times the number of categories in the theme times a set factor. The result should then be round off to the highest integer. The addition of the points can achieve the required points earned per category.

The set factor for the first iteration of the tool is proposed to be 0.8. This allows some categories to be of a lower level or even level 'o, not applicable for the project developer. This set factor can be changed after gaining experience in the feasibility of this number. It is possible that the factor needs to be adjusted to a lower or higher number.

Furthermore, the municipality also has the authority to set additional conditions to the 'level', which is further explained in chapter 6, in order to further specify the required circularity level.

The results

The results of the input of the the municipality will, alongside the form(figure 5.6), also be shown in radar charts. As can be seen in Figures 5.7 and in a glance, the levels of the three main themes for the project location. The bottom figure is the elaborated version of the top and shows the categories that belong to these main themes. Herein, the adjusted minimum requirements are shown per category and are governing to the main theme. The dark blue points are the average level of the main themes where the categories belong to. The white lines can be the adjusted and normative level of that category, but can also mean that, even if the main theme is on the same level. This specific category is required to be at the specified level and cannot be compensated by another category that belongs to the same main category.

Relation of the result on the project

The municipality can decide with the tool on what circularity aspects the project should perform both roughly and in detail- when needed. Responsibility for different circular goals can be introduced and appointed to different parties after the municipality set the performance level for these goals. The method can be used on any arbitrary location and ensures all projects will be tendered accordingly and systematically.

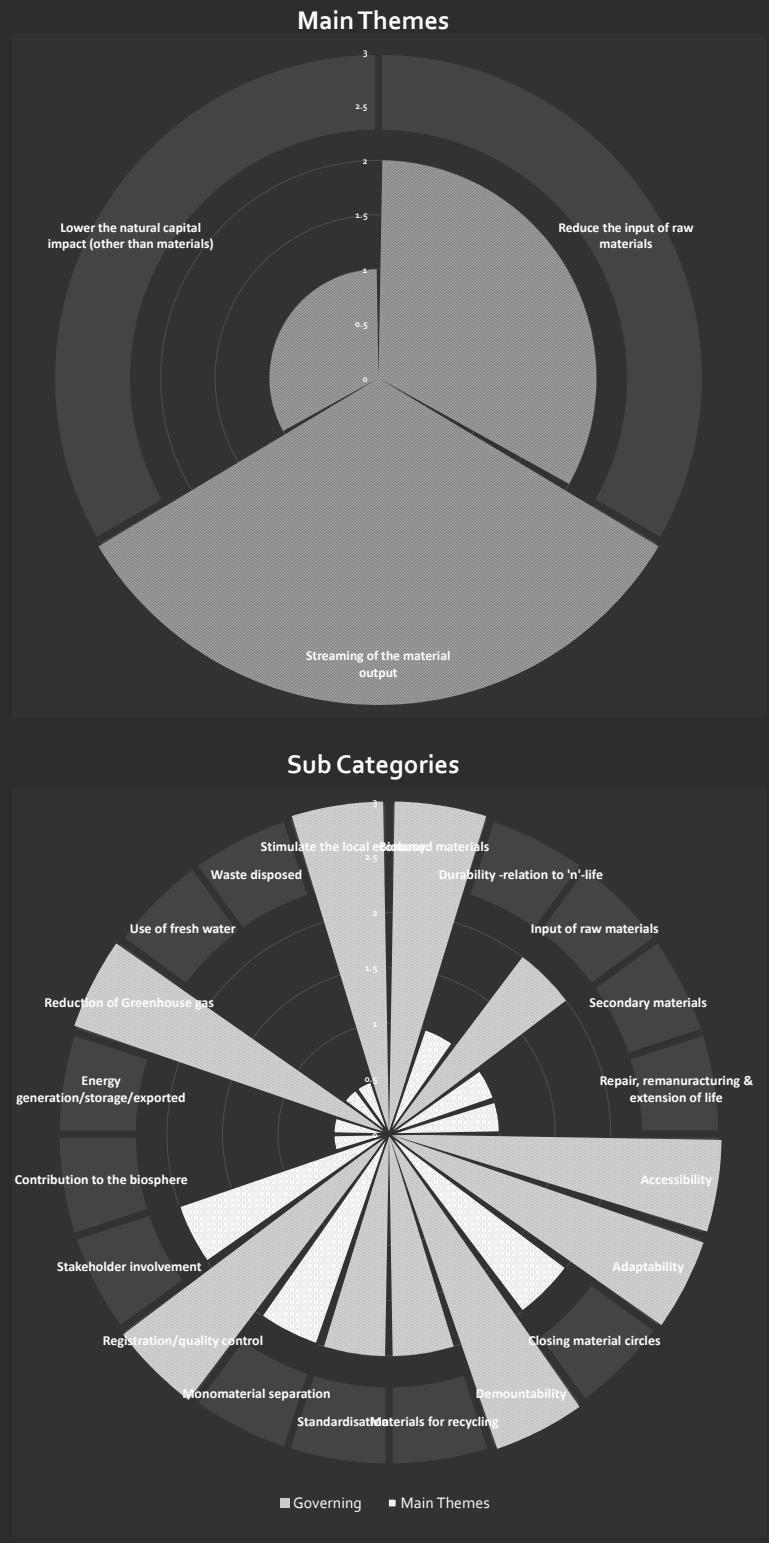


Figure 5.7: Output of the municipality. The main themes and categories. (Own figure)

The project developer

The project developer, together with its advisory organs need to assign the circularity levels to each category. The consequences of appointing levels to the different categories should be weighted against the feasibility and the the possible profit that can be achieved on the project.

Working on the tool for the project developer

The project developer's ambition is divided into two parts: the project's questions and the assigning of weighting points. The first part of the tool consists of a questionnaire (figure 5.8) related to the project: The project scale, the circumstances of the project (is it a new building or does it concern a renovation, etcetera), the durability, location factors, but also the future plans of the building and whether or not scalability, movability of the building should be taken into account. The purpose of this first part of the tool is that, based on the answers given, several tender categories will be discarded from the tool based on their relevancy.

The second part (figure 5.9) is the assigning of the weighting factors to the categories and the respective subcategories. A minimum number of points, determined by the municipality, need to be divided over these categories and subcategories. It is thus possible for the project developer to formulate the most effective measures and goals.

The functionality of the tool for the tender

The output of the tool will be the following two diagrams of figure 5.10. The Bottom diagram is the tender inquiry, which shows the level per the category that needs to be achieved by the project team. As can be seen, the output is the governing value of the project developer and the municipality. In this diagram, the project developer needs to set some categories to a higher level as now the municipalities values are higher in those categories (but the picture shows how the tool works). The top diagram is the output of the level per subcategory. This is a more detailed version of the first diagram for a better tender specification, but the subcategory levels might be changed after the tender in the agreement phase as long as the categories' level will be achieved.

Relation of the result on the project

The output forms two clear diagrams of the ambition of the project developer and the requirements of the municipality. The first diagram shows the governing level of the municipality and the project developer together in such a way that it is not possible to prescribe tenders underperforming to the wishes of both parties. The submissions will mainly be tested basedon these categories (not subcategories per sé). The levels to achieve are clearly shown in advance.

Figure 5.8: Questionnaire for the project developer. (Own figure)

1.0 | Ambition Project Developer					
Questionnaire					
Subject	**Questions**	**Specifications on questions**		**Answer**	**Describe or Specify**
Project scale	Describe the project scale: How many appartments, and buildings and square meter facade will be built (or renovated). Are there more similar projects like this one that can be build comparably in the near future?			N.V.T.	
Project circumstan	Is the facade for a new building or does it concern a renovation ?		✓	Renovation	
	Are there areas that restrict the dimensions of the panels such as galleries?	*Specify the restrictions*			
	Are there restrictions to the thickness of the facade ? For instance due to galleries?	*Specify the restrictions*			
	Is there a preferred side to install the panels? (from the interior/exterior) because of hindrance?	*Specify the restrictions*			
	Is there a maximum weight of the panels/ m2 for instance because of the existing structure?	*Specify the maximum weight and r*	✓	Yes	
	Has the building site space to allocate installation gear, machines and material?				
Durability- n life:	Is the environment of the building exposed to influence on the life span of the chosen materials of the facade?- (Related to the environmental category for materials -Milieuklassen)	*Pollution, acid rain, traffic, salts, chemicals Noise, earthquakes or any other*	✓	Salts	
	What is the minimum life span of the building?	*Temporary(15)/30/40/50(trditiona*			
	Will the project be built in a Dura 2000 zone?				
Spatial formation:	Is there a specific material choice based on urban planning?	*Timber/ Bricks/ concrete,/ etc.*	✓	Yes	*Brick front facade*
Architectural influ	Is there a specific architectural typology based on urban planning?				
	Is the architectural value high and should it besupported ideas throughout the process?				
Convertible	Is there a change of function of the building planned?	*If yes, after 15/25/30/50 years*		30	
	Is the buildnig planned to allocate a different function over time?	*If yes: Describe*			
	Is it likely /possible that the height of the ceilings/floord will change in the future?				
	Should there be possibility to change the window or door areas in the future?				
Scalable	Is the building meant to change in size over time? Multiple answers possible		✓	Decrease: Entire facade to the inside	
Service &extensio	Is a service contract desirable?				
Registration &qual	Is there a rewarding system based on the circular promise made in the joint ambition?				

				Points	
Main theme	**Categories**	**Sub category (specification)**		**Points**	**Specify answer**
Reduce the Input of Raw Materials	Biobased materials		✓	3	*Describe or Specify*
		Wood	✓	0	*Describe or Specify*
		Bioplastics	✓	0	*Describe or Specify*
		Other natural material	✓	0	*Describe or Specify*
	Durability -relation to 'n'-life		✓	3	*Describe or Specify*
	Input of raw materials		✓	1	*Describe or Specify*
		Rare material	✓	0	*Describe or Specify*
		Packaging	✓	0	*Describe or Specify*
	Secondary materials		✓	3	*Describe or Specify*
		All use of secondary materials rec	✓	0	*Describe or Specify*
		Re-use of materials	✓	0	*Describe or Specify*
	Repair, remanuracturing & extension of life		✓	1	*Describe or Specify*
		Requirements Muncipality Theme Score		**2**	
		Requirements Muncipality Sub Theme S		**8**	
		Reduce the Input of Raw Materials		**11**	
Streamlining of the Material Output	Accessibility		✓	1	*Describe or Specify*
		Accessibility of the facade in gener	✓	2	*Describe or Specify*
		Accessibility of the elements	✓	1	*Describe or Specify*
	Adaptability		✓	2	*Describe or Specify*
		Adjustable	✓	0	*Describe or Specify*
		Convertible	✓	0	*Describe or Specify*
		Moveability	✓	0	*Describe or Specify*
		Refitable	✓	0	*Describe or Specify*
		Structural redundancy	✓	0	*Describe or Specify*
		Scalable	✓	0	*Describe or Specify*
		Versatile	✓	0	*Describe or Specify*
	Closing material circles		✓	1	*Describe or Specify*
	Demountability		✓	3	*Describe or Specify*
	Materials for recycling		✓	3	*Describe or Specify*
	Standardisation		✓	1	*Describe or Specify*
		Standardised Dimensions	✓	0	*Describe or Specify*
		Modularity	✓	0	*Describe or Specify*
	Half prefabrication =2, Totally prefabricated =3 on the building site	Prefabrication	✓	0	*Describe or Specify*
	Monomaterial separation		✓	1	*Describe or Specify*
	Registration/quality control		✓	2	*Describe or Specify*
	Stakeholder involvement		✓	3	*Describe or Specify*
		Service contract and maintenance	✓	0	*Describe or Specify*
		Knowledge transfer	✓	0	*Describe or Specify*
		Architectural influence	✓	0	*Describe or Specify*
		Requirements Muncipality Theme Score		**3**	
		Requirements Muncipality Sub Theme S		**22**	
		Streamlining of the Material Output		**17**	✗
Lower the natural (other than materials)	Contribution to the biosphere		✓	1	*Describe or Specify*
		Air purifiying	✓	3	*Describe or Specify*
		Contribution to biodiversity	✓	2	*Describe or Specify*
		Contribution to water	✓	3	*Describe or Specify*
	Energy generation/storage/exported		✓	1	*Describe or Specify*
		Energy generation during life time	✓	2	*Describe or Specify*
		Insulation level (bronze =1, silver=2	✓	3	*Describe or Specify*
		Energy exported	✓	1	*Describe or Specify*
	Reduction of Greenhouse gas		✓	2	*Describe or Specify*
		Greenhouse gas reduction in produ	✓	3	*Describe or Specify*
		Greenhouse gas reduction in transp	✓	1	*Describe or Specify*
	Use of fresh water		✓	2	*Describe or Specify*
	Waste disposed		✓	3	*Describe or Specify*
		Requirements Muncipality Theme Score		**1**	
		Requirements Muncipality Sub Theme S		**4**	
		Lower the natural capital impact (other		**9**	✓
Social Economic Be	Stimulate the local economy Describe the range in distance (EU/NL/City)		✓	1	*Describe or Specify*
		Local companies /technologies	✓	2	*Describe or Specify*
		Local materials	✓	3	*Describe or Specify*
		Creating Local jobs	✓	1	*Describe or Specify*
		Social Economic Benefit		**1**	✗

Figure 5.9: Input form for the project developer. (Own figure)

Subcategories of the Project Developer' Ambition

Comparison Municipality & Project Developer Ambition

Figure 5.10: Output of the project developer for the tender. Top subquestions, Bottom comparison municipality demand and project developer (Own figure)

§5.4.3 Architect

The part of the tool for the architect is based on the literature research that is conducted. Most questions that need to be answered by the architect or design team are about designing the product and building (concerning the building physics). There are just a few questions related to the transportation of the product. For examle, whether sustainable harvesting or gathering from the secondary market of the materials is considered.The architect's role is to integrate and think of circular strategies into the design of the project.

Working of the tool for the architect

The coloured columns of figure 5.11 indicate the actual answers that need to be provided. When additional information is required, a description is given on what that information should cover by the columns in front of the questions. These columns should guide the designer to comprehend the topic and the question's relation and prepare the designer for the categories. It should generate the project's overall design approach, and the results are projected in a radar chart to see if the design meets the requirements. Of course, alongside this tool, the project's concept drawings and other traditional products required for a tender should be delivered. Standard of proof requires concept drawings of that part of the project.

Contribution to the project

For the project developer, it is convenient to see if the architect or design team would be suitable for the project and could work with the other parties, such as the technical engineers and building physics consultants. Based on the answers given and the radar chart the architects's vision is noticable. The architect/ design team is made aware of the weighing factor and can thus, based on this picture, in an early stage, show its green design approach by choosing other, secondary or local, materials for example.

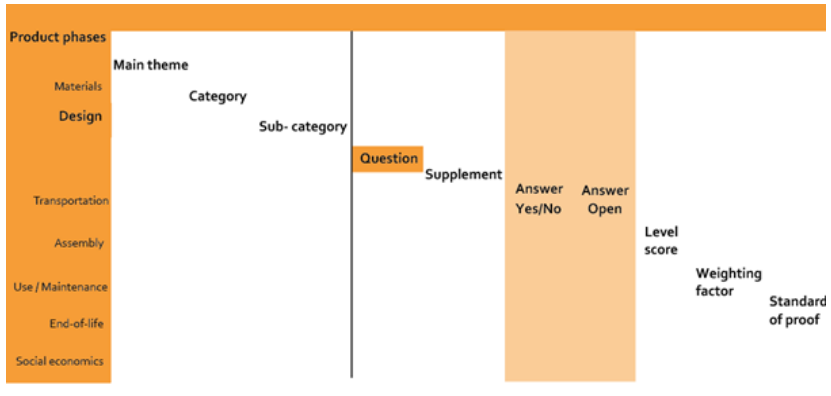


Figure 5.11:Input form for the architect or design team. (Own figure)

§5.4.4 (Facade) Contractor

This tab consists of questions focussing on the technical aspects and details of the facade. The following columns define the tab of the tool for the (facade) contractor: at the leftmost column, the order of questions is from top to down ordered to the product's life cycle phases(-figure 5.13). The columns next to this, show the main theme, category and subcategory of the question. In this way, it is made clear for the contractor what the topic of the question is. The column next to the subcategories shows the actual question(figure 5.12). Next to it, an explanation with the rules on how the answers are expected to be given. The question can be answered in the orange columns. It starts with a closed answer yes/no and follows with an entry for an open answer. These two have a distinction in colour to clarify that the user is expected to fill it in. The questionnaire for the (facade) contractor consists of more elaborated questions about the façade system and services they can offer compared to the tab of the tool that has to be filled in by the architect.

The tool for the contractor goes into detail on technical questions about assembly and materialisation, but also options about reverse logistics and so on. These question are based on the literature study that has been conducted for this research and especially focusses on chapter 2.5.

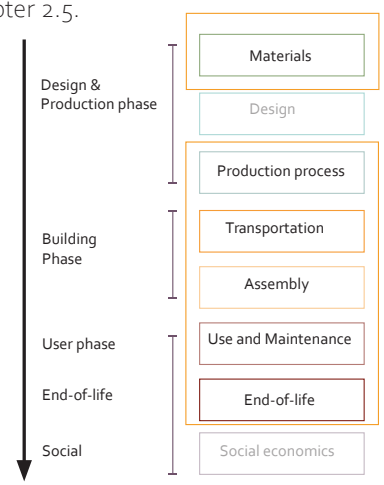


Figure 5.12: Order of the questions. (Own figure)

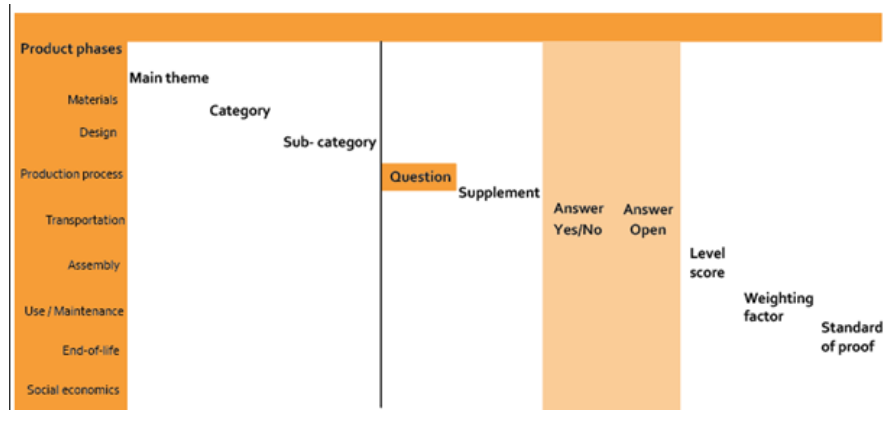


Figure 5.13: Input form for the facade contractor. (Own figure)

The output of the façade contractor
The tool's output is the answers given by the façade contractor and provided proof of certain questions. Alongside that, a radar chart is generated of the accumulated points of every subcategory. A comparison between the output of the project developer and the façade contractor's output is thus made visual.

The meaning of the result
The radar chart from the multiple (façade) contractors can be placed together in one chart to compare the circularity measures taken per party easily to objectively choose the project's right contractor, as can be seen below. The contractor can use the radar chart and output to determine if the offered product or services will suit the project based on the tender. In this way, excessive work can be avoided if the product or service appears not suitable for the project. For the contractor, it is also convenient to see what aspects of their services, suppliers, or products need to be improved on. In case the chosen façade system needs small improvements, for instance, by ordering from different (sub) suppliers, the tool creates grip and insight to stimulate an open discussion on how to improve on the relevant aspects.
(Facade)Contractor – monitoring
The tool should have the function to automatically calculate the average results for the whole façade: building level" based on the suppliers' inputs for the products, and the (façade) contractor input of the systems needs to fill in all the products and systems used plus the questions about the connections between these products and execution and assembly plan (figure 5.14).

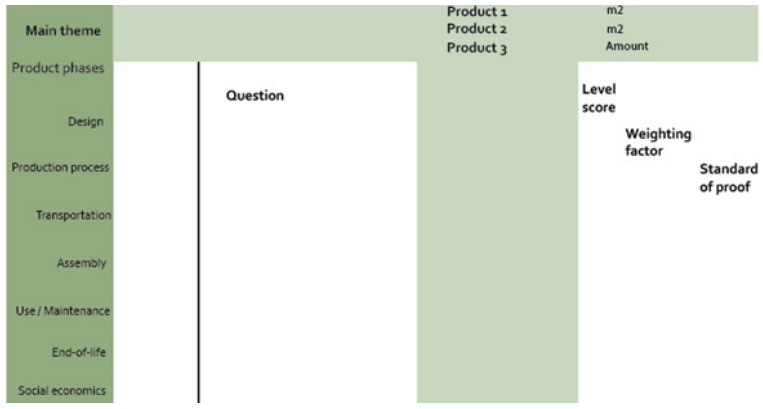


Figure 5.14: Input form for the project developer. (Own figure)

§5.4.5

The execution agreement
At the tender phase, the parties have been selected on obtaining the criteria on category level and specific demands that the project developer could indicate on subcategory level. However, as multiple parties will be united, more and diverse ways and insight in achieving these category levels will also exist. Therefore, after the key party selection, the project developer and the architect and (facade) contractor can further agree on and specify the circular ambitions for the execution. In this phase, the contracts will be signed, and arrangements can be made. This also implies that all parties together will agree on all the (minimum to achieve) levels of the subcategories. Figure 5.16 shows the topics on which can be discussed. For example, the parties could function as a design team and divide the profit, making it possible to write down a higher ambition than the minimum to achieve the goal when this could lead to an economic incentive. The column that shows the minimum level is defined by the tender's points (defined by the project developer and municipality). The right column shows the final scores for the subcategories as agreed through determining the subcategories. These subcategories will show the categories' final score (in dark green) and need to be just as high as the minimum level (figure 5.16). Figure 5.15 shows the radar chart. As can be seen, this agreement needs higher levels on several subcategories of adaptability.

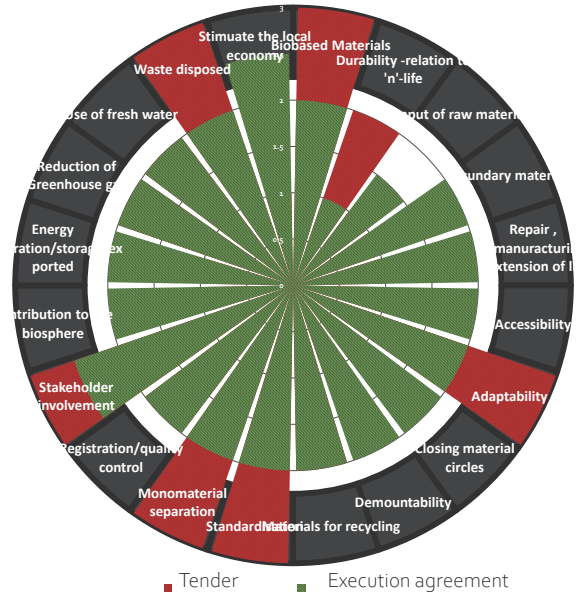


Figure 5.15: Comparison on categories tender requirements (red) and execution agreement. (Own figure)

Assigning the points

The most right column shows the assigning of levels of the categories in the executed agreement. The maximum of its subcategory determines the points of the categories in black. Thus, in the category of Biobased material: the highest points of wood, bioplastic or other natural capital is weighted. The average of its subcategories determines the value of the 'normal dark green categories. This is, for instance, the case with the category adaptability. The yellow categories have no subcategories (figure 5.16).

3.0 | Execution Agreement

Main theme	Categories	Sub category (specification)		Minimum level	Specific topic /descripti	Ambition (higher than minimum)	Dependent on:	% Tailings chance of the higher	Proof for validation	Bewijslast aangelev	Final Score	Final Score
Reduce the Input of Raw Materials	Biobased materials		✓	3			Yes				2	2
		Wood	✓	0							2	2
		Bioplastics	✓	3							2	2
		Other natural material	✓	0							2	2
	Durability -relation to 'n'-life		✓	3							1	1
	Input of raw materials		✓	1							1.5	1.5
		Rare material	✓	3							1	1
		Packaging	✓	0							2	2
	Secondary materials		✓	3							2	2
		All use of secondary materials re	✓	0							2	2
		Re-use of materials	✓	0							2	2
	Repair, remanufacturing & extension of life		✓	1							2	2
Streamlining of the Material Output	Accessibility		✓	1							1.5	2
		Accessibility of the facade in gener.	✓	2							2	3
		Accessibility of the elements	✓	1							1	1
	Adaptability		✓	3							1.5	2
		Adjustable	✓	0							1	1
		Convertible	✓	0							1	2
		Refitable	✓	1							2	3
		Scalable	✓	0							2	3
		Structural redundancy	✓	2							2	2
		Moveability	✓	0							2	2
		Versatile	✓	0							2	1
	Closing material circles		✓	1							2	2
	Demountability		✓	3							2	2
	Materials for recycling		✓	3							2	2
	Standardisation		✓	3							2	2
		Standardised Dimensions	✓	2							2	2
		Modularity	✓	3							2	2
	Half prefabrication =2, Totally prefabricated =3 on the	Prefabrication	✓	3							2	2
	Monomaterial separation		✓	3							2	2
	Registration/quality control		✓	2							2	2
	Stakeholder involvement		✓	3							2	2.5
		Service contract and maintenance	✓	0							2	2
		Knowledge transfer	✓	0							2	3
		Architectural influence	✓	0							2	2
Lower the natural ca (other than materials)	Contribution to the biosphere		✓	1							2	2
		Air purifiying	✓	3							2	2
		Contribution to biodiversity	✓	2							2	2
		Contribution to water	✓	3							2	2
	Energy generation/storage/exported		✓	1							2	2
		Energy generation during life time	✓	2							2	2
		Insulation level (bronze =1, silver=2	✓	3							2	2
		Energy storage/exported	✓	1							2	2
	Reduction of Greenhouse gas		✓	2							1.5	2
		Greenhouse gas reduction in produ	✓	3							2	2
		Greenhouse gas reduction in transp	✓	1							1	2
	Use of fresh water		✓	2							2	2
	Waste disposed		✓	3							2	2
Social Economic Ben	Stimulate the local economy Describe the range in distance (EU/NL/City)		✓	1							2	2.5
		Local companies /technologies	✓	2							2	3
		Local materials	✓	3							2	2
		Creating Local jobs	✓	3							2	2

Figure 5.16: Execution agreement .(Own figure)

§5.4.6 **The supplier**

The supplier needs to fill in the questionnaire about their product(5.17). These questions are product, service, and production-related. Most of the questions for the tool are related to chapter 2 of the literature study. The supplier usually owns the product declarations of their standard sub-suppliers for specific parts of the product, and therefore, the sub-suppliers do not necessarily need to fill in the tool on their own (based on the interview with suppliers). In this phase, most questions can be answered with closed answers (yes/no or multiple choice), but the open answers option stays available to allow for an explanation for an innovative solution.

Standard of proof is also very important. Building information models (BIM) can complement the answers given, just like showing ownership of the product's certificates.

The lay-out of the tool for the supplier

The tool for the supplier is divided into two parts. In the first part, the supplier should fill in the materials per element of the product, the density of these materials, the information about the life span of each of these elements, the intended life duration of the product, and the mass % of each element in the product.

The second part is based on the composition of these elements. Most of the questions can be answered by selecting the element and answer the question per each element. It is thus possible to give closed answers to the questions based on the input of the first part of the tool. This provides the opportunity for an (interactive) direct diagram output to see the influence of each choice of the product for the supplier to learn from through this process. Appendix A gives a proposal to see the influence of the product on the environment to "calculate" the improvement.

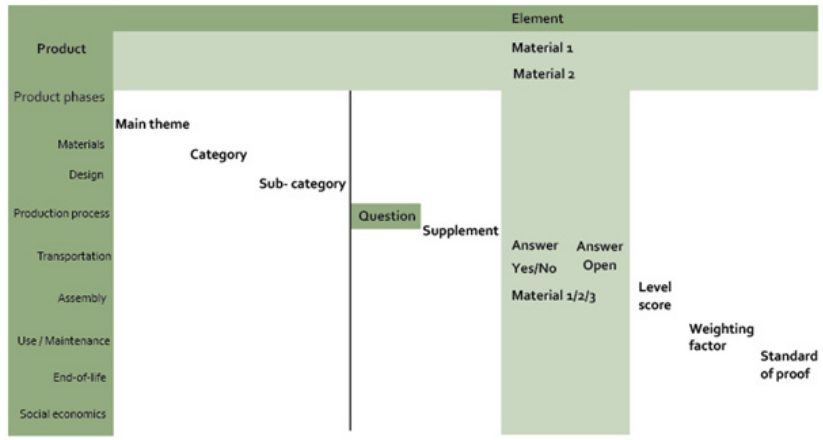


Figure 5.17: Input form for the supplier. (Own figure)

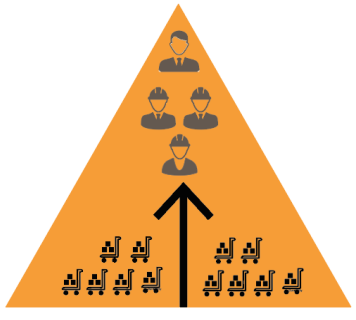
The suppliers should fill in the tool for their product and use it as a design roadmap to improve their existing products. When more tenders use this method, analysis can be conducted to draw a relation in the market demand on circular aspects, and priority can be given to those aspects in the Research and design facility. Apart from that, it is also possible to examine the selling points of the product in circularity. Figure 5.18 shows the radar chart of product improvement due to a taken measure as output from the tool (blue without and red with improvement).

The tool's subsequent development could be that once a complete analysis on a product with this tool is executed, the results could be stored to be used again in a different tender. The results then should be stored in a national public database accessible for the parties upfront, such as architects or contractors. In this way, it becomes possible to search in this product database and filter on the preferred circular aspects to choose the best suitable products already in an early design stage, which may lead to the stimulation of bottom-up initiatives.

Analysing the market vision

Examine selling points of the product

Design roadmap for a more circular design



Buttom up

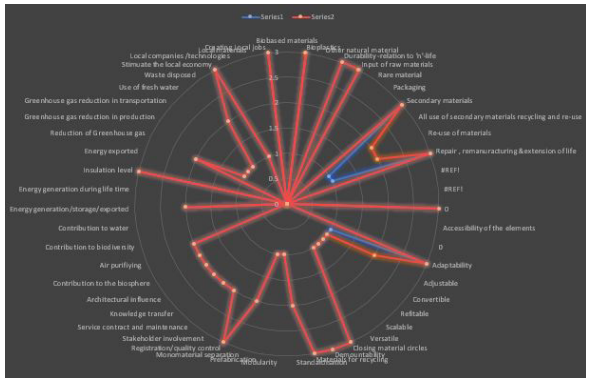


Figure 5.18: Product improvement. Red line:New improved and Blue: Before measure.(Own figure)

§5.4.7 **Dashboard**

The dashboard function (figure 5.19)keeps track of the process by monitoring the set goals during the project to make necessary adjustments possible. This dashboard function could be used during meetings to show the bottlenecks per party. The dashboard, therefore, can be used to start discussions on the needed circular topics. Every party will have its dashboard where it can check its product or service to the service agreement. One chart will show the total project's data, which the assembler of the facade will fill in. In this way, all key partners will stay updated and check their influences on the project when they change the design.

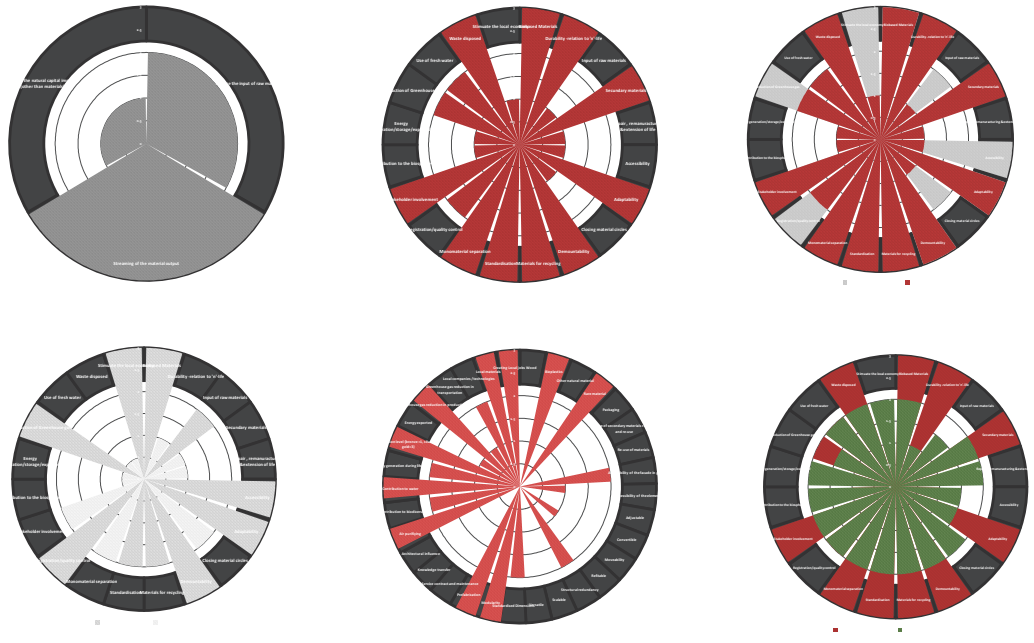


Figure 5.19: Dashboard function. (Own figure)

5.5 Concept evaluation

The concept will in this part be evaluated on the brief from the first paragraph of this chapter.

The tool should avoid utilising multiple-choice options as it may obstruct innovative answers.
The tool uses multiple choice answers. Most questions should be answered with "Yes/No"; however, the answer should also be complemented with an open answer for a real 'judgement.'

The tool should avoid reinventing the wheel so that double work can be avoided.
By allowing to fill the tool with answers to existing tools results such as the MPG specified on one theme and nationally recognised, this tool can maintain overview.

To prevent the tool from outdating, it should be updatable where irrelevant topics can be deleted and replaced by new, more relevant ones.
This should be possible.

The tool should be flexible enough to cope with multiple levels of information from global to precise, as not all information is known beforehand, while also precise information is required to avoid that the tool promotes greenwashing.
This is done in two ways. First, the tool has multiple tabs corresponding to the party or phase of the project. The questions are thus organised according to the level of detail. The second way is through the way of answering the questions. Where the Municipality has only multiple-choice, the architect, engineers, and contractor need to answer open questions. Thus, at the execution phase, the facade contractor and supplier will mostly answer again with closed answers and refer to the elements and products in the answer.

The tool should enhance collaboration

The method itself is based on collaboration as it requires every party to take an active part in the procurement. The agreement needs to be filled in with every key-party and through the dashboard function that makes monitoring possible.

Allow parties to take an active part in the circular ambition

All key-parties are included in the tool. The data must be filled in by the suppliers, as well as the (facade) contractor, and the Municipality (or other public authority) has an important role.

The tool should give and enhance an overview for all parties
All parties should gain insight/understanding of their choices.

Interactive radar charts and the dashboard function are made to compare the influence on the whole project.

Divide responsibility to parties- clear agreements
Through the excecution agreement.

Monitoring should be possible to give an overview and keep track.
This is done through a dashboard function.

Verification at the end of the process should be possible.
The results of the levels can be compared to the original goals and ambitions.

Prevent greenwashing
Through precise information about the products , connections, and processes.

Stimulation of innovation with open questions.
This is possible.

Flexible answer levels. Not everything is known at the start.
Therefore the tool uses multipe tabs for the different phases in the procurement.

Divide circular economy into aspects and let the initiator choose the importance.
The circularity aspects are divided into the three main themes of the circular economy, and the municipality can globally indicate the importance of each of them through the tool. This will correspond to a certain amount of points. The project developer can go into detail and divide the weighting factor of each category.

Divide questions based on the required knowledge of the people.
The questions are ordered in the life phases of the product. This will make it possible for the companies to answer the questions.

Allow change during the design process
Mainly the facade contractor has two functions in the tool for which one is based on changes. An absolute score should be the output for the tender to compare systems/ parties.
Included

The assessment method for building products should be based on the principle of the circular economy.
Check

The contract should contain a minimum to acquire environmental goals.
The execution agreement is based on the minimum goals, but there is space to aim for higher ambitions. This depends on the project developer.

Realistic project ambitions.
This still has to be tested but can be adjusted with a factor (of which a first trial is the 0.8 value)

Data driven procurement for transparency.
There are not (yet) data-driven questions asked. The concept of the tool is not about gathering information through external influences. However, the suppliers need to fill in or provide information about their products and processes that should be verified.

§5.5.1 Conclusion

The ambition formulated by the design brief is thus accomplished as the points described here are included in the tool.

Chapter 6

Validation of the procurement tool

§6.1 Casestudy Reigersbos
§6.2 Evaluation casestudy
§6.3 Verification of the circular procurement tool
§6.4 Test of the tool
§6.5 Summary

After introducing the concept of the circular economy procurement method in the previous chapter, this chapter will evaluate and validate the method. Paragraph 6.1 will introduce the case-case-study project 'Reigersbos' on which the method will be applied. Paragraph 6.2 will evaluate the method on useability. The current process of setting circular ambitions for the project has been compared with the same process but with the tool's help.

Paragraph 6.3 is about the verification of the circular procurement tool. Interviews with experts have been conducted to collect feedback on this circular procurement method in terms of functionality. The results will be described in this part of the thesis. In Paragraph 6.4, the assessment function of the tool will be tested on product and system level. Paragraph 6.5 closes this chapter with a summary.

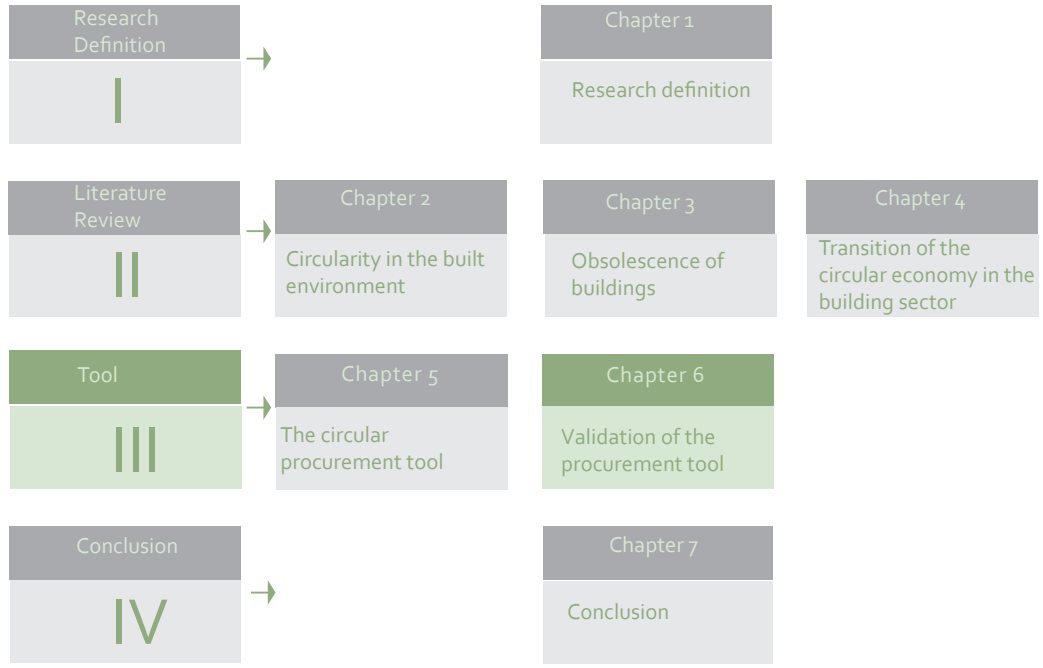


Figure 6.1: Place of chapter 6 in the thesis. Source: Own figure.

6.1 Casestudy Reigersbos

The tool evaluates a mid-rise residential project, which is a renovation project located in Reigersbos Amsterdam. This paragraph will introduce the project.

Amsterdam wants to become energy neutral in 2040, and one of its pilot areas is Amsterdam Zuidoost. The citizens of this area work with the municipality of Amsterdam, companies, and universities on the first project, "Urban Energy Lab Zuidoost," together to obtain this goal. The Urban Energy Lab has joint forces with the TU Delft and many other partners (such as the AMS institute, Climate KIC, the Universiteit van Amsterdam and Amsterdam University) to help the transition towards a scalable renovation strategy. The Energy Agreement for Sustainable Growth (SER 2013) and Climate-KIC have aimed to renovate annually 1.000.000 dwellings a year to achieve a carbon-neutral building stock on the EU level by 2050. The project Urban Lab Zuidoost recognizes excellent benefits for improved health and comfort conditions, elimination of fuel poverty and will create new local job opportunities during the technical upgrade of the existing buildings stock as it foresees that the transition towards renovation solutions is not a technical question only but also asks for a social change. Local manufacturing and other jobs will play an important role in addition to the coalition agreement.
Reigersbos is an apartment complex in Amsterdam Zuidoost that consists out of 288 houses divided over 10 blocks(-figure 6.3). One apartment will be transformed into a demonstration house that will be used as a test for this project at the end of 2020. In this pilot project the energy and façade concept will be installed and monitored with the idea of being scalable to other renovation project in order to accelerate the transition towards an energy neutral Amsterdam Zuidoost area and beyond.

§6.1.1 Reigersbos apartment complex

The Reigersbos apartment complex-(figure 6.2) was built in 1984 as a social housing complex owned by the 'Stadgenoot'. Nowadays, a minority of 40% is still owned by Stadgenoot while the rest belongs to ten small vvE's.70% of the tenants of Stadsgenoot must vote for the renovation just like most of the VVE owners. As the ambition of Amsterdam Zuidoost is to be energy neutral in 2040, also this apartment complex needs to be renovated. The VVE aspires to renovate Reigersbos to the level of NOM(+). This level is related to the insulation of the facades and the climate concept, regulated by installations such as solar panels and shared heat pumps. Thus, the building will generate more energy than the user theoretically needs while eliminating natural gas. Since the concrete floors and walls are still in good shape, no adjustments are required. Because this project is a deep renovation related to the facade and installation, the money will come from the VVE with national grants, Return on investment (NEF-gebouw gebonden financiering). and investment funds in building-owned financing.

The advantage for the user is saving energy costs yearly and a comfortable and healthy living condition inside. Solar panels at the roof of the building will generate electricity, an underfloor heating system will regulate the user's thermal comfort, and a CO_2 measuring system will control the ventilation inside a house.

Most of the apartments only have a front and back facade as a building envelope (figure 6.4). However, the condition of the facades is poor and needs replacement. In several apartments, there are moisture and infiltration problems. The existing window frames are made of non-thermally broken aluminium. The thermal leak can be noticed on a performed thermographic recording where the glazing is better insulating than the window frames. Furthermore, the ventilation grilles, also included in these frames, allow draught to pass through. In the demo house that has been visited, the closed façade parts consisted of just a Trespa plate and were insulated with an extra insulating plate. Some of the cladding even consists of asbestos.

The site visit showed that the occupants only heated the living room regularly to save on costs. As a result, the bathroom is now covered with black mould due to moisture. Every apartment has horizontal partitions, either a gallery or roof terrace. Many complaints are about leaks, most of which resulted from the poor quality of the roof coverings.

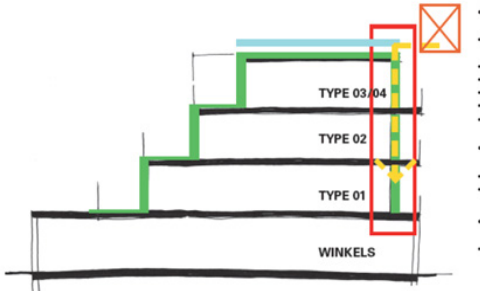


Figure 6.2:Reigersbos apartment complex-Top: section of the renovationin green.bottom impression.(own figure)

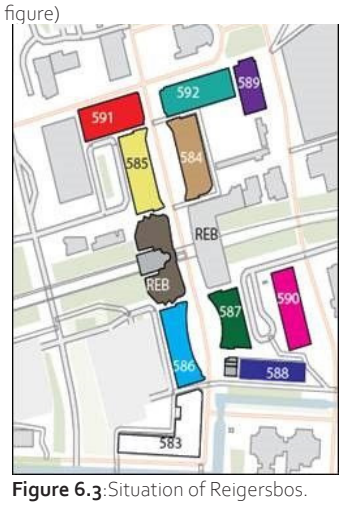
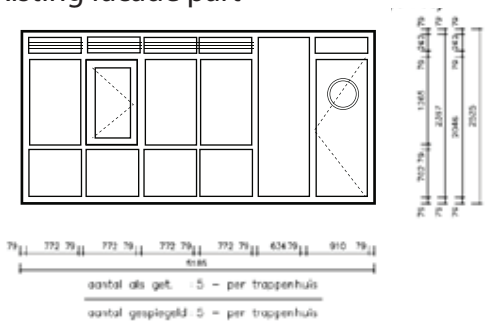
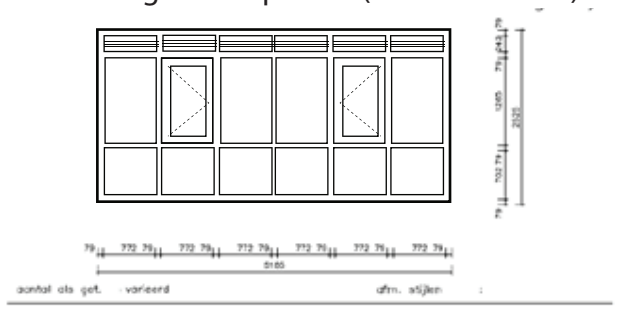


Figure 6.3:Situation of Reigersbos. Source: Gemeente Amsterdam

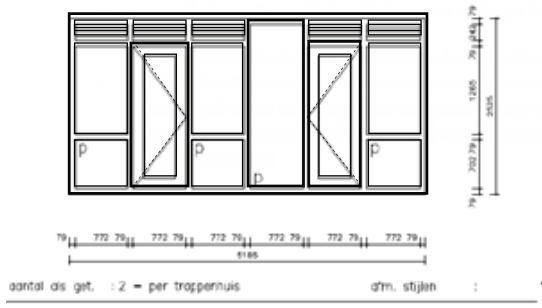
Existing facade part A front



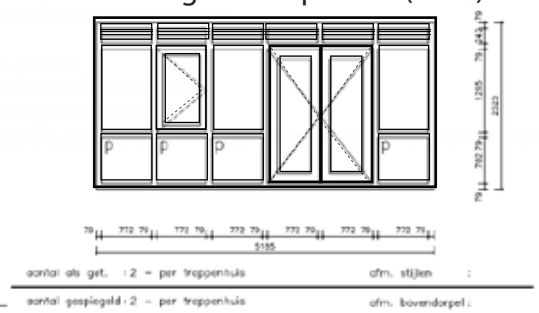
Existing facade parts B (front and back)



Existing facade parts C (back)



Existing facade parts D (back)



Existing facade parts E (back)

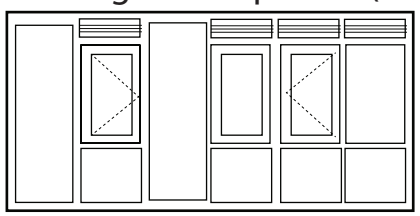
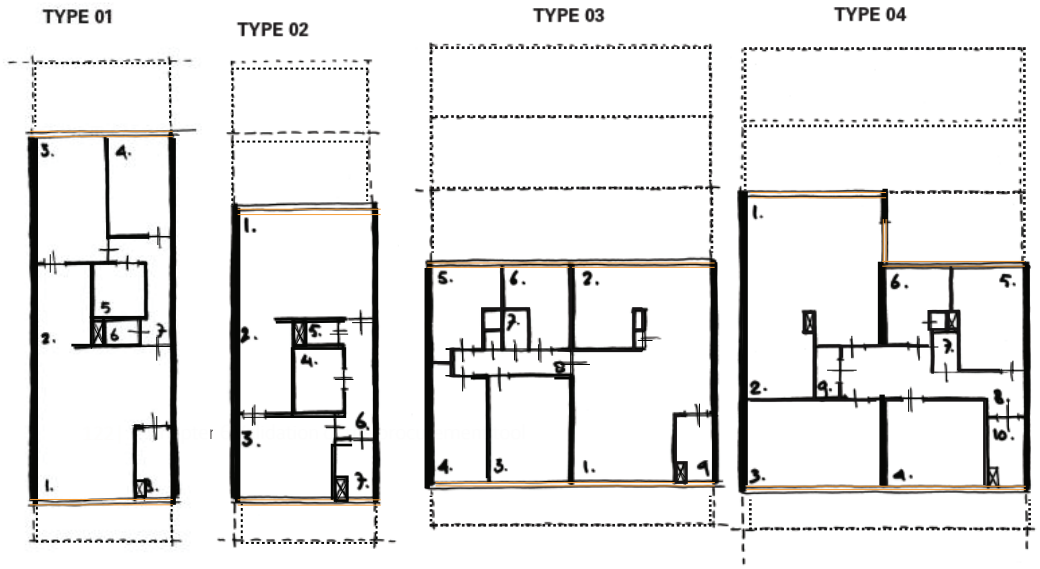


Figure 6.4: The apartments inside the building blocks have four different types
The existing facade has 5 different panel types (Based on documents retrieved of Gemeente Amsterdam)



When considering renovation projects, several aspects need to be considered that form boundary conditions that newly-built projects do not have to deal with. The following have been noticed in the project Reigersbos. The balconies need extra insulation as they form the roof of the apartments beneath them. The galleries with beams can obstruct accessibility for the assembly of the facade onto the building, and narrow passageways can become too narrow when the newly placed facade becomes thicker(figure 6.5).

Figure: 6.5: Renovation boundary conditions: (Own figure)

6.2 Evaluation casestudy

The deep renovation assignment came as a question from the ten VVE's of Reigerbos to the municipality of Amsterdam. The VVE's are the client but didn't have any money for a renovation, and without the help of the municipality and a financial plan, there was no possibility to renovate the apartments to make them natural gas-free by 2040. The municipality is in this project just the process supervisor and will look after the construction process. The municipality brought together the many parties (figure 6.7), but Klimaatmissie united the facade suppliers and installation suppliers. Stichting!Woon further supports the residents as an advisory organ. As can be seen, many parties are involved.

The cost limit of the façade has been settled and corresponds with a certain service contract (gold, silver, or bronze according to the energy efficiency of the façade and installations). In the case of the Reigersbos, the golden package seemed to be financially most favourable over a period of 30 years. The packages gold, silver, and bronze, which can be selected by the VVE's and Stichting Woon, are composed together with the architect. The choice for a certain level of energy efficiency is decided with the VVe's that represent the residents. During the first stages of the project, phases I and II of figure 6.6 have shifted around very often, especially during the first realisation of the first demo house.

Key partners

General contractor
Facade contractor
Building services
Municipality
Bank
Energy Service company

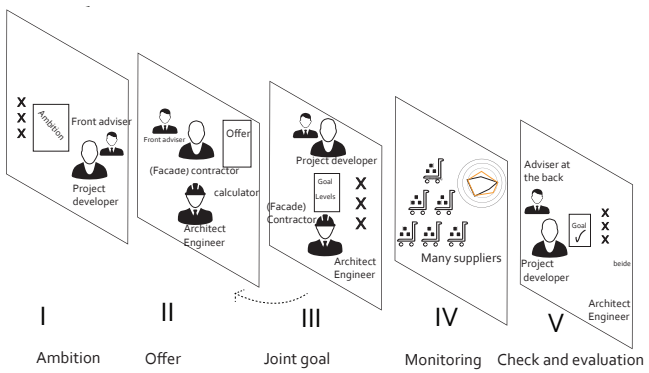


Figure: 6.6: Key partners in the procurement process: (Own figure., 2020)

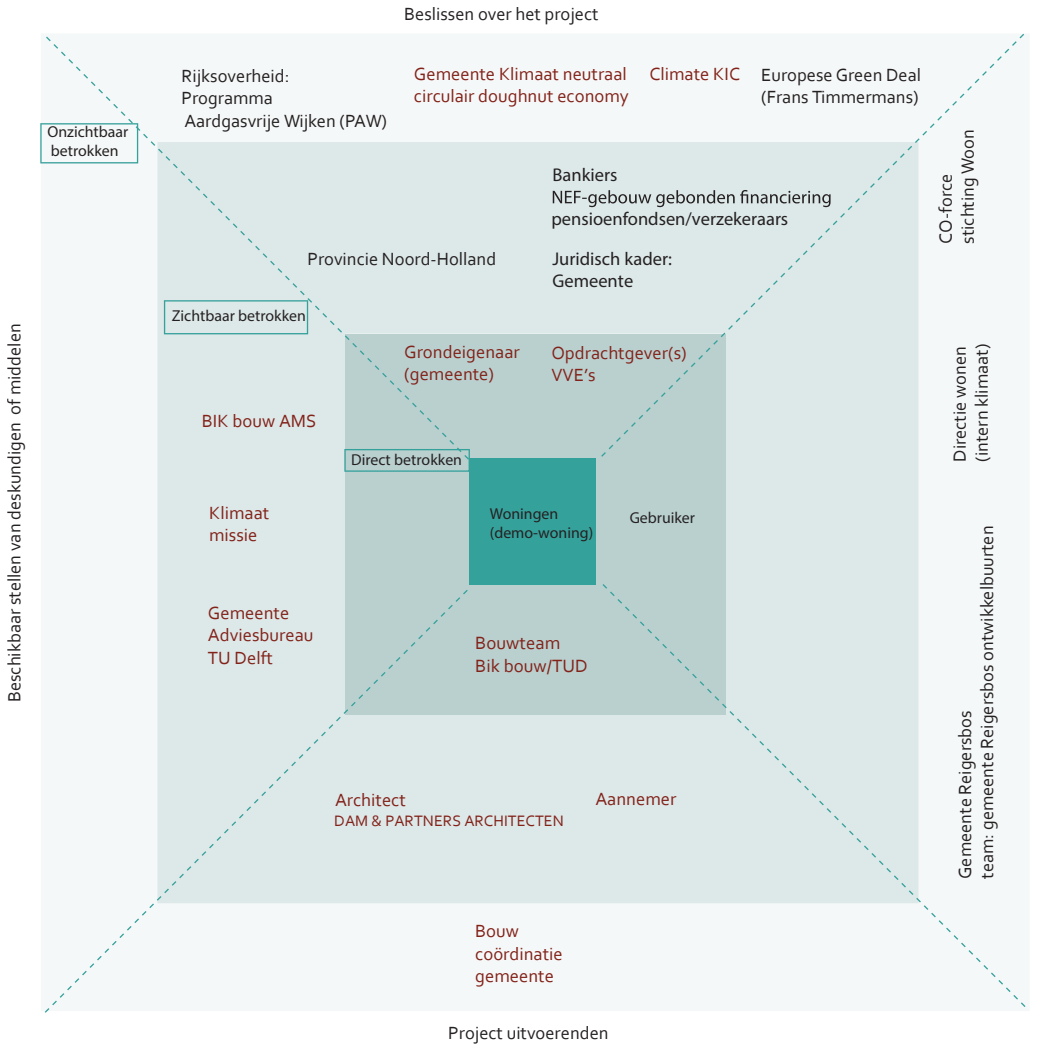


Figure 6.7: Parties involved in the Reigersbos project. Based on Gemeente Amsterdam

§6.2.1 The municipality

The Municipality of Amsterdam has constructed a roadmap to include sustainability in tenders. Even though this is still in development. Many aspects of the circular economy have already been taken into account for the design of the Reigersbos project. The main focal point is the service contracts of chain parties. For instance, Climate-KIC organised a model for a corporation that helped suppliers and execution parties to develop a revenue model in which the dependencies of each party and liabilities is arranged. Another big circular aspect is the requirement of creating new local job opportunities during the technical upgrade of the existing building stock. This requirement was implemented as the Municipality foresees that the transition towards renovation solutions are not only a technical assignment but also an assignment to improve social inclusiveness. Furthermore, future proof, upscalability and, of course, the elimination of natural gas during the user phase is the main criteria the Municipality has come up with as the landowner. As can be seen, the Municipality has recognised the need for a structured process to establish the requirements. This tool, as it is specifically suitable for the renovation of facades could offer more grip on the many aspects of circular projects. Taking advise from the front-advisor would become easier as the topics would be schematised. Communication towards the project-developer would also be more clear, and evaluation of the circular ambitions could become possible.

Gemeente Klimaat neutraal and Climate KIC: They could advise and tell the Municipality (as landowner) which circular topics are the most important to focus on and what minimum level it should have.

Klimaatmissie, Bik bouw AMS and Gemeente Adviesbureau could function as the front advisor of the Municipality at the first step(I) Ambition. Their advise can be made explicit and well- structurally processed. In the existing situation, Klimaatmissie has brought the parties together. This tool could have helped to find parties that are willing to work together and share the same vision.

§6.2.2 The VVE's

The ten VVE's are the initiator of the project. In this renovation project, the main concern is to keep it as economically beneficially as possible while improving the comfort level of the apartments. The VVE's have approached the Municipality of Amsterdam and Stichting !Woon for help and guidance to make the renovation possible, meanwhile the users of the building does not have to pay significantly more than they do currently if future maintenance cost is taking into account. The requirements are the following: better-insulated facades, a private ventilation system for each apartment and reduce maintenance to a minimum.

Filling in the tool as a project developer would, in this case, be outsourced to Gemeente Adviesbureau, as they have assisted the VVE's and thus can be seen as their advisers. The input of the VVE's will be included in the project developers set of requirements, alongside the wishes of the municipality. The requirements of the project can be seen in figure 6.8. As can be noted, the formulation of general requirements could have been avoided, as the regulations define acoustic and fire-proof requirements. In this case, the requirements were not specific enough to evaluate them at the end of the project.

§6.2.3 The architect and contractor

For this project, a design team works together for better communication and integral knowledge exchange between the professions. Both are taken into account by Klimaatmissienederland and BIK bouw AMS . Though they still need to decide on the usual design choices of materiality. For example, choosing the material of the window frame,or the choice of cladding. The tool could offer an overview of the possibilities and show through a dashboard how the design choices influence the circularity of the façade. Choosing a certain insulation type would influence the panels' required thickness while also the potential material utility factor; the contract possibility and warranty of the supplier should be taken into account. It forces the architect to also think about the options at the end-of-life. Thus, it can help the architect and design team structure the design decision process while maintaining the usual design process for innovation and creativity. The tool could also assist with monitoring during the process and at the end for evaluation. After this, the results of the tool will be kept alongside the information of the façade to check on the maintenance of the building and at the end-of-life. This to ensure the suppliers of the project will stay responsible for their products.

§6.2.4 Municipality

In the role of coordinator of the process, the municipality could check on the monitoring and eventually the evaluation. However, it would be the role of Klimaatmissie to show that the project requirements have been realised as agreed.

Furthermore, the tool offers transparency to stakeholders that are not necessarily using the tool constantly, which makes it easier to notice if the project could be funded or qualifies for a grant (such as Nationale warmtefonds or for an ELENA grant (European Local EnergyAssistance) a grant for a big scale energy project by a local municipality or Renovatimotor for project costs etcetera.). But also, for example, investors that are interested in the sustainability and innovation of the project.

A large part of the Reigersbos project is setting up a financial system to make it possible for VVE's to join their buildings' renovation process. The tool is also not suitable to include the humanity approach applied in Reigersbos, for example, where improvement of the interaction with the community was achieved. Therefore it only focuses on the technical part of the circularity of the façade.

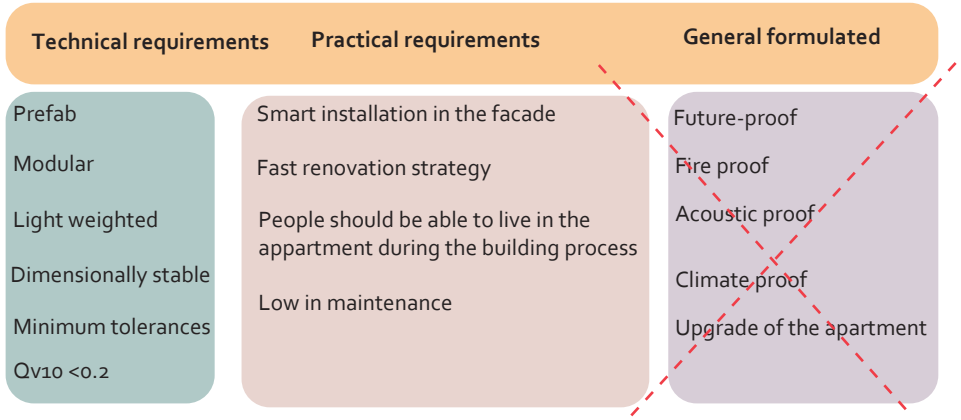


Figure 6.8: The technical, practical and too general formulated circular and sustainable requirements according to the ambition of project Reigersbos. Own figure

6.3 Verification of the circular procurement tool

After explaining the concept of the tool, a verification of the concept is needed. The procurement tool is intended to be used by multiple parties such as the municipality, project developer, architect or design team, suppliers and (façade) contractors. A market analysis of these parties over the tool is chosen as a verification method. Experts from these disciplines are asked to give feedback on and are asked how the procurement tool can be helpful and could work for their approach. The interview questions are chosen to be qualitative as the reply should refer mainly to the usability of the tool, which asks for open answers rather than a fixed range of answers typical for a survey.

§6.3.1 Method

One week in advance of the actual interview. All interviewees(Table 6.1) received the tool and a manual with a short description and clarification of the words and definitions used within the tool. They also received a few presentation slides that consisted of information about the tool and a short explanation of the part of the tool meant for the interviewee. This way, the interviewee can look at the tool, explore and form their opinion about it without too much explanation from my side to see if the tool was organised clearly and obtain information about the tool's usability.

The interviews were divided over two months to improve the concept and the tool itself in between (figure 6.9). The actual interviews lasted approximately an hour. The first part of the interview was mainly regarding explaining the tool's goal and the necessity of a circular economy, while at the same time, there was a possibility to ask the interviewee their vision and experience.
.

• **Role**	• **Company/Institution**	• **Name of interviewee**
• Municipality	• Municipality of Amsterdam	• Maaike Zwart, Salomé Galjaard, Lianne Hulsebosch
• Project developer	• Stichting Woon	• Baudoin Knaapen
	• Rijksdienst voor Ondernemend Nederland	• Rutger Snoek
• Architect	• Klimaatmissie Nederland	• Bouke Staphorst
• Facade concultant	• Frontwise facades	• Dominique Vosmaer
• (Facade)contractor	• Ferlem	• Jan Deckers
• Supplier	• AGC	• Anton Peters

Table 6.1: Interview of the following field experts. (Own table)

of circular aspects in projects. After this short discussion, questions tailored to the job function of the Interviewee were asked. The following themes were asked to all interviewees:

- In what way the can the tool be helpful for the party?
- How would use of the tool lead to improvement on the facade design in the project?
- At which point in the process would they make use of the tool and for what purpose?
- What are the obstacles of the use of the tool?
- How would the tool be used, and what are the functions they are looking for?
- What functions are missing in the tool?
- Would they like to use the tool as a design roadmap?
- What do they think of privacy problems?
- How can this method lead to better communication and transparency between parties?

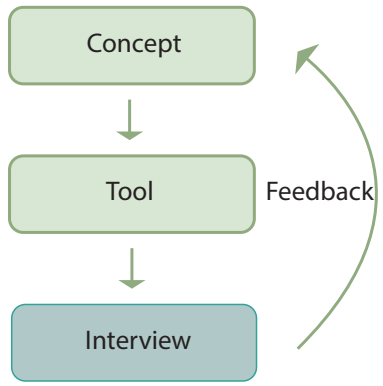


Figure 6.9: Scheme of the influence of the interviews

§6.3.2 Answers

It is not realistic to assume that one person knows every detail of all phases of a product, services of the company, and transportation-related. Most probably, knowledge is divided over multiple people in the company. Hence it is convenient that the questions are split into product phases for multiple people to fill in their knowledge without internal discussions needed. This will make the tool more efficient.

The most circular ambitions should be set at the start. Once the municipality sets the first requirements, there is no incentive for the project developer to exceed this. Project developers are only interested in implementing circularity in the project if it can lead to a business model where the circular measures' investment costs can result in financial benefits. Thus, the municipality's important task is to set the standards at the ambition phase for circularity high.

The interviewees mentioned that the amount of information asked by the tool was considered much. However, they also replied that the tool is less prone to greenwashing because of the many specific questions that need to be answered. This distinguishes the method is different from the existing tools.

Most interviewees appreciated the tool because of the visually strong radar charts that make it easier to compare systems or choices. Furthermore, the option of interactivity in the tool is interesting. This could be enhanced when parties could check on one another to check if they are still on track with the project's circularity goals. Based on this idea, the tool has integrated a 'dashboard' function. This dashboard can be used to oversee the project. It can be used during meetings between parties and can help prevent issues that may occur with a change of decisions during the project.

Multiple interviewees answered that project teams often achieve a better integral result than individual parties. The tool can open discussions between architects, energy, and building system consultants to align parties during the process. The agreement offers the possibility to set up a revenue model compared to a design team, where profit can be divided between parties for an integral approach and better monitoring during the project. In this way, cooperation and transparency will be enhanced.

From the interviews conducted, it is also clear that not every company uses the same definition of circularity but has formed its idea, making circularity susceptible to greenwashing. The idea of the circularity for this tool is based on the principle itself, and by introducing this tool, the principle must be explained clearly to prevent misconception. Furthermore, it is even more important that each subcategory's weighting factors will be shown at the tender initiation.

Municipality
The municipality would be interested in the tool once project developers would be willing to work with this method. The main concern of the municipality is asking a too high ambition at the initiation of the tender. The risk is that no party could fulfil these ambitions, and as a result, the project can not start. The municipality is also afraid that the circular ambition will be scattered over too many categories, leading to inefficient measures. Another remark on the tool is that it is only focussing on the facade, while a procurement will most likely involve a complete building.

To cope with demanding too high ambitions, a correction factor has been introduced on the set ambition score that the tenderer needs to achieve. This factor is set to 0.8. Since the categories are arranged on the main theme, the scattering will be restricted. Furthermore, the tool can, in a later stage, be expanded to installations and constructions.

Project developer
There is not just one standard way to start a tender or procurement, especially with negotiated tenders. From phases 1 and 2, respectively, the project ambition and offer (figure 6.6) multiple conversations can take place with the market and with project developers. The project developer would always prefer to be aware and informed by the market in front of the start of the tender to formulate realistic requirements from market aspects. However, process a general situation that can apply to many projects. The concern of the project developer is that circular ambitions are set too high on categories that are not in line with an optimal business plan for the project developer, while, for instance, with the ambitions differently organised per category, a higher total score could be achieved.

The architect or design team
The architect stipulated that facades for renovation and newly built buildings differ on several aspects, a clear distinction should be made and the differences should be taken into account. For example, with renovation one must take into account the situation of occupants regarding installation time or installation place. Renovation projects have also different, mostly limited, boundary conditions regarding the accessibility to the façade, this is already described in paragraph 6.1.

According to this remark the tool has integrated the option to choose between a newly built or renovation project. Dependent on the choice of the project developer, non-relevant questions will be eliminated in the part of the involved parties.

The architect also suggested that it would be interesting once a design choice is made, for instance, about the material, the architect would get to see what kind of rules are connected to this decision. For example, the choice for timber is only sustainable when the lifespan of the product made out of that timber exceeds the tree species' renewal rate. In this way, the tool can also work as a roadmap and database for the architect. In this way, the tool will not be seen as a design obstruction but more as a guiding tool since the architect can still overrule the tool's advice.

In this first procurement tool version, this idea is not applied as in order to make this work, many information and restrictions need to be analysed. It would only be possible in combination with another tool such as a database like "GRANTA EduPack 2020."

However, the architect responded that the tool could already be used as a guide when the radar chart will be interactive even without this function. This will lead to a better understanding of a decision and, therefore, result in a better design solution rather than replacing the design process, leading to generic solutions.

(Façade)Contractor
Ferlem, contractor and supplier, answered that the tool is interesting because it offers the possibility to overview the sustainable goals of the project at a glance which makes it less time consuming to decide if their product would fit the requirements of the project without the need to read the whole brief first. Ferlem suggests that an automatic point generator should be provided. This could, for example, be provided in a different part of the tool that can assist the contractor/supplier to decide on what level the product scores on a certain subcategory.

Furthermore, the tool provides insight on what specific circular aspects the product can be improved on. The tool can be useful to improve the existing product. Implementing circularity in the design is only appealing when the sales numbers will significantly increase Hence, the project is big enough. Suppliers usually have already an arrangement with their sub-suppliers for the existing product. Changing the sub-suppliers to increase sustainability will only be worth it in case the project is big enough. The tool, however, can form a framework to openly discuss the possibilities for improvement. This could also imply for following projects. Contractors can learn from the results.

Scheldebouw as a facade suppliers has already experiented with choosing suppliers based on lower CO_2 emissions for aluminium facade products. However, retrieving the right information seemed very hard, as not all suppliers are even aware of the differences between post-consumer and pre-consumer recycled content. The database of GRANTA Edupack or ICE (also used for Breeam) are programs that can be used to compare the embodied carbon emissions for facade solutions. Scheldebouw has its own department that generates a database of its suppliers based on CO_2 reduction (Jansen, 2021). The tool that allows for assessing elements or products from different suppliers would be a reasonable next step.

In the Netherlands, most projects will not hire a facade contractor or let this party be involved already at the agreement phase. Having just the overall contractor as a key party may result in a less ambitious agreement as the overall contractor may lack knowledge about the available products and possibilities. This makes the phase at the start of the tender more important, where the municipality will start with the desired circular ambitions that must be met.

Suppliers

Parties such as suppliers often have information about their product that they do not want to share with rival companies. When using a tool that focuses on transparency and reveals every detail of the product and process may result in fear that their information is revealed, which could form an obstruction for this tool's use. A solution could be that the tool would only show the important output needed to offer protection of information. Furthermore, with BIM, a lot of exact product information is already stored and used in models. AGC added that the products just need to show the label of their certifications, but only people with an arranged visit can see the exact product declaration. Something similar could be proposed for the information of the procurement tool, showing the important output only that is needed while the protection of information is still guaranteed.

From the supplier's perspective, the tool can provide the opportunity to improve their products based on market demand. Nowadays, it is not always known which sustainable innovation should be prioritised for further technical development. This leads to a high amount of inefficient product development. The tool can show the market demand by analysing the tender requirements. This information could save on materials and money for suppliers.

The issue with the tool could be that the major product selection should already be chosen at the agreement phase since this is the most important moment where parties will set promises and goals based on the available product options. This usually implies the products they are familiar with. Once the agreement is set, the contractor's ambitions will not be raised on the ground of a higher sustainable score. However, this could change when a new database, in addition to the NMD, would store all the needed information of the verified products. In this way, bottom-up initiatives can stimulate the circular transition as well. By adding the product to the database, all main parties can notice and use the product already in an early stage of the design by filtering certain circular qualities. Nowadays, innovation in products often gets neglected due to the lack of awareness of their existence by the involved parties such as the architect or design team.
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§6.3.3 Summary

To verify the procurement method, several interviews with field experts have been conducted. The field experts are categorised according to the roles given in the previous chapter. The interviewees consisted of municipality, project developer, architect, (façade) consultant, (façade) contractor, and supplier. The interviews were conducted in two months. The feedback collected from these interviews formed the basis for updating the concept of the tool.

An insightful and comparable result
According to the interviewees, the tool requires enough input to prevent greenwashing. Therefore, by using the circular procurement tool, every party will be assessed with the same definition and framework of the circular economy. Since the tool does not merge multiple categories to achieve one score but rather shows the result using radar charts on every (sub) category, the results are clear and suitable for comparison. The tool may lead to a more integral project approach as it enhances collaboration between parties. Furthermore, the tool can provide the opportunity to open up discussions based on the (sub)categories. Monitoring between parties can result in a higher chance of reaching the set goal.

The radar charts make a quick overview of the required tender goal possible. This overview makes it less time-consuming to decide for contractors if and which product would fit the project requirements without reading the whole brief first.

It is said that the tool supports the design process, which can lead to responsible and knowledgeable decisions rather than replacing the design process to generate generic solutions. The tool does also allow for circular improvement on product and system level. Both contractors as suppliers could be based on the tender requirements improve on their products or stimulate development in a specific direction. The tool, when further developed, may lead to bottom-up initiatives when verified products could be stored in a database that allows choosing products already from the start of a project.

§6.3.4 Discussion

The interviewees' selection was based on their function in the building industry and how likely they are to use the procurement tool. The list of interview participants should expand, with more than three participants for each function at least. Furthermore, remanufactures, and parties working in the recycling industry, and private project developers should also be interviewed.

6.4 Test of the tool

A small test is conducted on the tool . To start with the smallest scale, a building product is used for the first simulation with the tool. The test is conducted with the tab of the supplier. An insulated glazing unit (IGU) is chosen because it is the most common building product found in the built environment and is largely known as a linear product where much improvement in terms of circularity can still be achieved. This conventional IGU has been compared to a circular design proposal of a previous project called 'The re-seal window'. The goal is to check whether or not this design is also more circular according to the tool.

§6.4.1 The building products explained

The conventional IGU consists of two layers with argon gas in between (figure 6.10). The spacer bar that contains desiccant is placed between the glass panes at the edges. The sealant bonds the glass panes and spacer bar structurally together while sealing the cavity hermetically from infiltration of water vapour or leaking of gas between the panes. The problem of a conventional IGU is that added elements such as coatings, foils for laminated glass and the sealant prevent the IGU from being recyclable, as the prevailing glass industry requires high quality and clean ingredients only. This makes the IGU a finite, single-life product resulting in almost 125.000 tonnes of post-consumer glass waste each year in the Netherlands. The IGU works optimally as an insulating element as long as there is dry (argon) gas inside the glazing panes. However, the life span of current IGUs is just around 15-20 years and is dependent on the butyl seal, which is just 0.1% of the weight. In the current design of the IGU, no refurbishment is possible, meaning that the glass panes and the spacer will not be re-used, but instead end up as landfill while these materials exceed the life span of the sealant by a large margin (Veer, 2016).
The re-seal window design focuses on the possibility of remanufacturing the IGU. The design utilises a detachable and interlocking butyl seal that functions as dry gas and vapour barrier and a hollow section that assures the tightness of the seal and offers the possibility to replace the weakest part of the whole glazing panel every ten years so that the glazing panes and the spacer bar can have a life span of more than 100 years. The glass panes are glued onto the spacer bar with UV glue that can be separated at the end-of-life when heated above 150 degrees Celsius.

§6.4.2 Filling in the tool

To answer questions in the tool about the manufacturing process of the conventional IGU, the EPD has been provided by the company AGC(see Appendix C), while the production and assembly process of the IGU has also been explained during an earlier company visit. The Re-seal window uses for this research the same materials and aluminium spacer bar to estimate a comparable EPD when needed (the material of the spacer bar in the original re-seal design is from glass-fibre instead of aluminium).

§6.4.3 Conclusion of the test with a product

The radar chart (figure 6.11) shows in which specific topics the Re-seal window performs better than the conventional one, and by looking at the diagram, it is also clear on which points the product could be improved to perform even better at circularity (table 6.2). Not all topics are relevant in an IGU design, such as contribution to the biosphere, but for example, the contribution to water can be improved by using less Net water at production. This information is retrieved from the EPD, and the product's certificates (Cradle to Cradle Certified) shows the improvement of this specific product compared to a reference product. The re-seal window is not Cradle to Cradle Certified, which is noticeable among other categories in the use of freshwater.

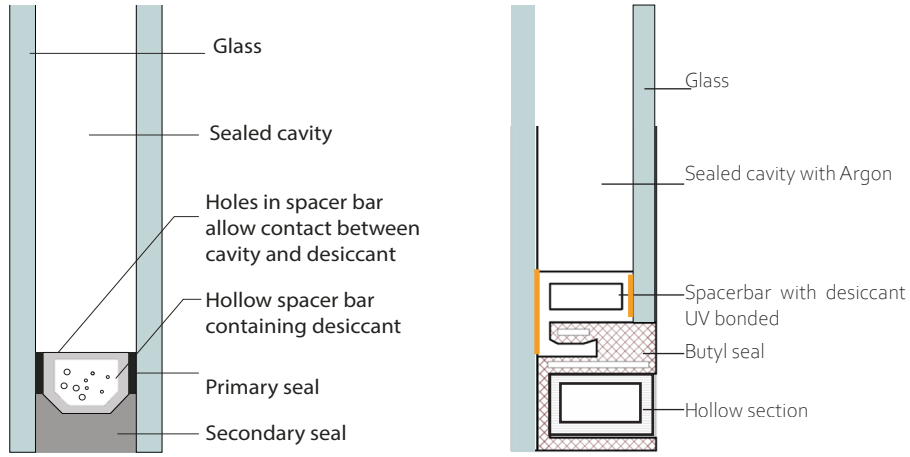


Figure 6.10 : Crossection of a conventional IGU l(left) and The reseal window(right) (Own image).

categories	IGU jm pr	IGU AGC pr
Biobased materials	1	1
Wood	1	1
Bioplastics	1	1
Natural material other than wood:	1	1
Durability -relation to 'n'-life	3	2
Input of raw materials	3	1.5
Rare material	2	2
Packaging	3	3
Secundary materials	1	1
All use of secondary materials recycling and re-use	1	1
Re-use of materials	1	1
Remanufacturing and other circular strategies	3	1
Accessibility	0	0
Accessibility of the facade in general	0	0
Accessibility of the elements	3	1
Adaptability	2	1
Adjustable	1	1
Convertible	0	0
Refitable	0	0
Scalable	1	1
Structural redundancy	0	0
Moveability	0	0
Versatile	0	0
Closing material circles	3	1
Demountability	2	1
Materials for recycling	3	1
Standardisation	2	2
Modularity	2	2
Prefabrication	0	0
Monomaterial separation	3	1
Registration/quality control	3	3
Stakeholder involvement	2	2
Service contract	3	1
Knowledge transfer	3	2
Architectural influence	1.5	2
Contribution to the biosphere	1	1
Air purifiying	1	1
Contribution to biodiversity	1	1
Contribution to water	1	2
Energy generation/storage/exported	1	1
Energy generation during life time	0	0
Insulation level	3	3
Energy storage	1	1
Reduction of Greenhouse gas	2	2
Greenhouse gas reduction in production	2	2
Greenhouse gas reduction in transportation	2	2
Use of fresh water	2	2
Waste disposed	1	1
Stimuate the local economy	0	0
Local companies /technologies	2	1
Local materials	1	1
Creating Local jobs	3	1

Table 6.2 : Result of the comparison between two building products (Own image).

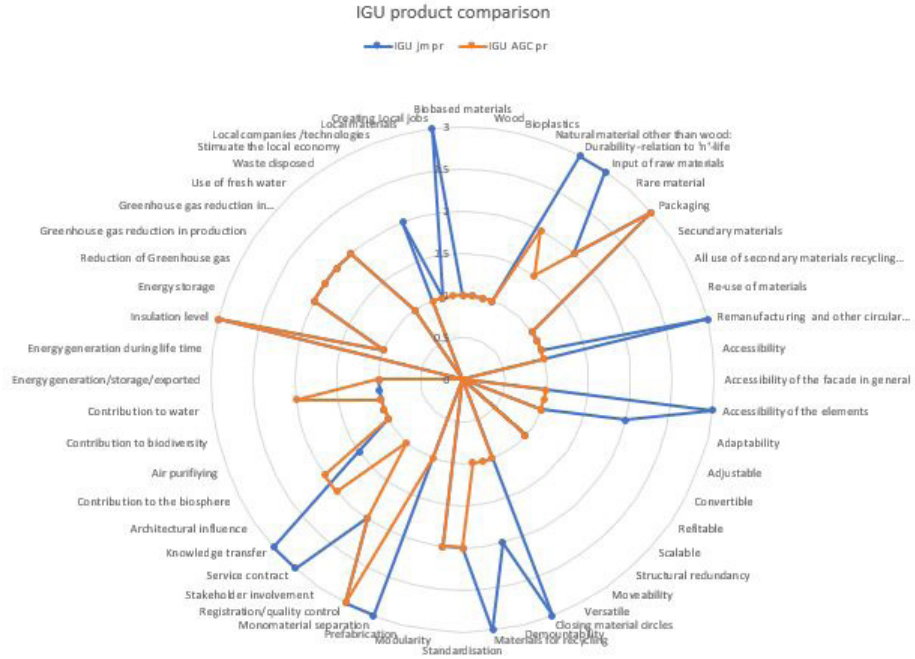


Figure 6.11 : Result of the comparison between two building products in a radar chart . (Own image).

§6.4.4 The test of a system

The second test of the tool is conducted with two building/ facade systems of which only the façade elements have been taken into account. The façade elements of Ferlem and Strotec have been compared with each other by simulating first on a product basis (the tab that the supplier has to fill in) and secondly as the complete building system which covers the connections and assembly between products.

Both systems' information is retrieved by contact with the companies, interviews and product and assembly information available on the website. The systems are already discussed in chapter two.

§6.4.5 Conclusion of the test with a system

The radar chart shows the comparison of both systems in absolute grades, and thus their advantages are clear from a circularity perspective (figure 6.12). On the topic where Strotec achieves higher levels in biobased materials, Ferlem offers better options regarding service contracts and prefabrication possibilities, and because the company and technology are from the Netherlands, the local economy is stimulated. From this test, the product of Strotec achieves higher scores in all three circularity main themes (figure 6.3). It must be noted that the tool only focuses on circularity and not, for instance, on the ease for the user such as smart technology or the elimination of several installing companies for electrics, etcetera.

Main theme	Categories	Ferlem	Strotec
Reduce the input of raw materials		8.5	9
	Biobased materials	2	3
	Durability -relation to 'n'-life	2	2
	Input of raw materials	2	2
	Secundary materials	1	1
	Remanufacturing and other circular strategies	1.5	1
Streaming of the material output		14	17.5
	Accessibility	2	2
	Adaptability	1.5	1.5
		1	1.5
	Demountability	1	2.5
	Materials for recycling	1	2
	Standardisation	3	2.5
	Monomaterial separation	1	2
	Registration/quality control	1.5	2
	Stakeholder involvement	2	1.5
Lower the natural capital		7.5	9.5
	Contribution to the biosphere	1	1.5
	Energy generation/storage/exported	1.5	2
	Reduction of Greenhouse gas	2	2
	Use of fresh water	1	2
	Waste disposed	2	2
	Stimuate the local economy	2	1.5

Table 6.3 : Result of the comparison between two facade panel systems. (Own image).

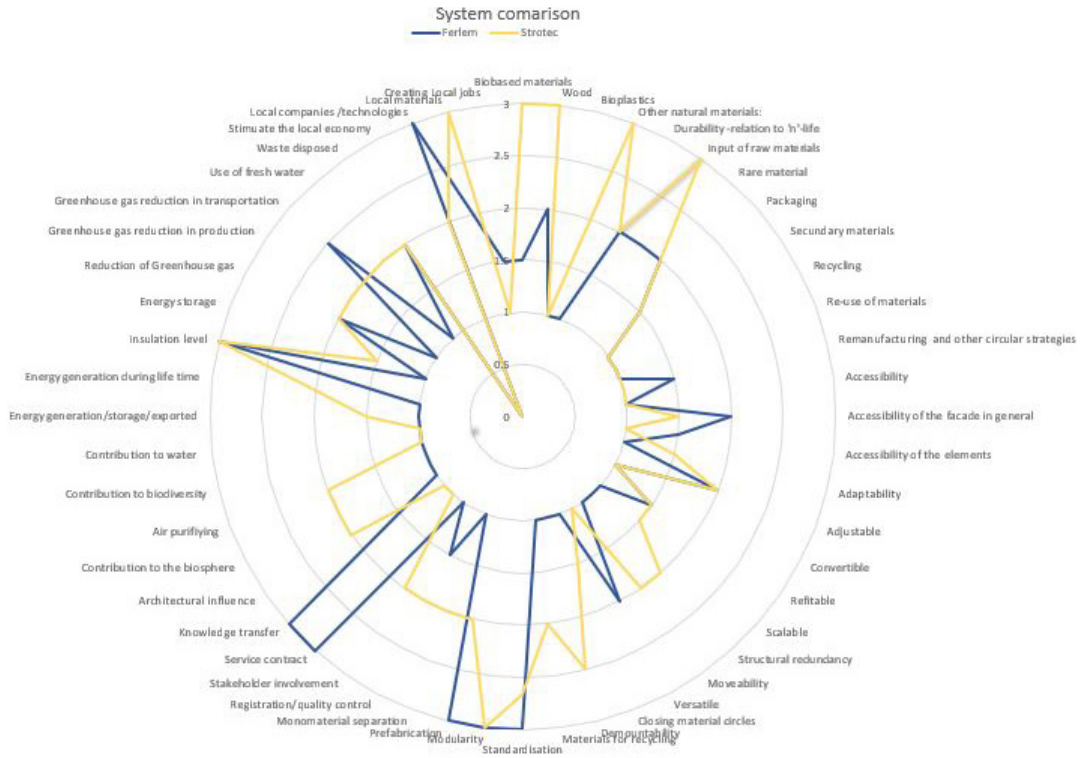


Figure 6.12 : Result of the comparison between two building systems in a radar chart . (Own image).

§6.4.6 Discussion

Some subcategories, such as 'convertible', are not applicable to a building product but are only relevant when a whole system is analysed.

The way the categories handle the score of the subcategories differs per category. The category: Biobased materials, takes the highest points among the subcategories wood, bioplastics, or natural material other than wood. This is because it wouldn't make sense to choose the mean value in this case, as a product that consists of 90%of wood and ten per cent of bioplastics would perform. When evaluating the comparison between systems, the amount of points low according to the calculation because the individual subcategories would get low points. This would unnecessarily have a negative influence on the score. While with the category accessibility, the average of its subcategories should be taken. All weighting points of the subcategories are equally (1); this, however, is not correct. From a material perspective, it would make more sense if re-use would weigh higher than the recycled content in the category of secondary materials. This is because for the recycling batch, usually also new raw materials are added. Appendix A introduces a way how these weighting factors could be determined more accurately.

per main theme seems almost impossible to reach. In the example level, three needs to be achieved in the main theme, 'Reduce the input of raw materials. This corresponds with a minimum of 12 points. When taking a closer look at the categories in this main theme, it means that for both the categories 'biobased materials and 'secondary materials', a high level needs to be achieved to satisfy this requirement. This would unnecessarily make it too difficult. When chosen for a high level in the category biobased materials, the category secondary materials can almost not be classified high as well. This is because biobased materials, especially in the category 'other than wood', should be at their best state, which implies raw materials instead of secondary. It is recommendable that the formula must be changed with the correction of 1 category less(new formula table 6.4): Even now, non of the systems seems able to achieve level 3. However, if remanufacturing of the systems is possible, it could be achievable according to comparison the new formula Because the tool has not been completely tested using multiple building products for a system. The next step should consider multiple façade panels, the IGU and a window(frame) to test the tool with ratios of building products.

The levels are comparable to the Ambitieweb but are not 'noted' exactly per subcategory with the exact requirements yet. Therefore it is still sensitive for different interpretations.

Furthermore, the factor of 0.8 has been taken into account as described in paragraph 5.4.1

- *Level* — *Amount of categories in the theme* — *factor* — *value* — *Required Points*
- *3* — *5* — *0.8* — *12* — *12*
- *2* — *9* — *0.8* — *14.4* — *15*
- *1* — *5* — *0.8* — *4* — *4*

Old formula

- *Level* — *Amount of categories in the theme* — *correction* — *factor* — *value* — *Required*
- *3* — *5* — *1* — *0.8* — *9.6* — **9.5**
- *2* — *9* — *-* — *0.8* — *14.4* — **14.5**
- *1* — *5* — *-* — *0.8* — *4* — **4**

New formula

Table 6.4 : Comparison of the required points without (old) and with correction factor of 1 category (Own image).

6.5 Summary

The project developer and municipality have a big influence on the initiation of circularity in the project as they can translate their circular ambitions into requirements for the tenders. The more circular projects are asked for, the more advisers, contractors, and suppliers have to implement them into the design. Purchasing power can be utilised as an accelerator of the circular economy. However, the lack of knowledge and experience in demanding these circular requirements in the tender forms an obstacle in most building projects.
.
The circular procurement tool concept is a standardised framework that should help the municipality and project developers translate their circular ambitions into tender requirements. The tool works for an arbitrary project location. Furthermore, the tool can transparently assess façade products and systems by showing the individual benefits of the products' circular measures. Therefore, different parties can use the tool and throughout the whole design process, as became clear from the verification of interviews with field experts.

The Municipality of Amsterdam has recognised the need for a structured process to establish circular requirements for procurement. This circular procurement tool offers more grip and overview of the many aspects of circularity in the built environment, as seen in the evaluation with the tool on case study Reigersbos. Communication on circularity would become easier since the categories offer a schematic framework that can help translate the circular ambition into requirements that evaluate the tender possible instead of using general and arbitrary formulated sustainable ambitions.

Because the tool offers transparency and a quick overview, it is also easier to notice if the project could be funded or qualifies for a grant. It may even lead to more trust for key partners. As became apparent in the case study project Reigersbos, renovations projects ask to include the humanity approach as more stakeholders (users) are involved. The tool, however, only focuses on the technical part of the circularity of the façade.

The tool is tested with a comparison of two building products and a comparison of two façade systems. The radar charts show the results per circular (sub)category in absolute grades, which is needed for a clear assessment.

The next test with the tool should be conducted using multiple building products for a system, where multiple façade panels, IGU's and window frames are combined. This is with the current version of the tool not possible yet as the tool should therefore take into account mass percentages of each product. Furthermore, a clear requirement should be written on the specific meaning of levels 1, 2, and 3 per subcategory as is done for the Ambitieweb. Without this, the tool will be susceptible to different interpretations. Furthermore, each subcategory still uses the same weighting factor (1). It is also recommended to distinguish these weighting factors based on the improvement this subcategory brings for the circular economy. A method on how this can be done is proposed in Appendix A.

IV

Chapter 7
Conclusion

§7.1 Discussion
§7.2 Conclusion
§7.3 Recommendation

7

This final chapter of the research is grouped into three sections: paragraph 7.1 will sum up the discussion, paragraph 7.2 will conclude on the work and answer the research question of this thesis. Paragraph 7.3 will cover the recommendation for further research. The relation of chapter 7 to the whole thesis can be seen in figure 7.1.

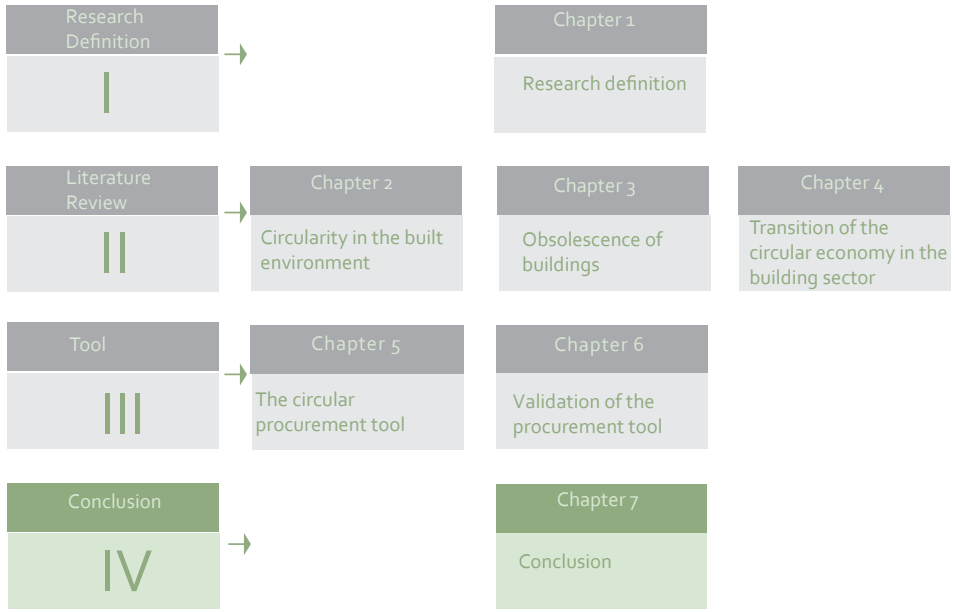


Figure 7.1: Place of chapter 7 in the thesis. Source: Own figure.

7.1 Discussion

This paragraph will point out the most governing discussion points regarding the thesis.

The research did not carry out a sensitivity analyses to determine the score of the weighting factor of each subcategory. This could be beneficial for the thesis to further validate the final tool.

The requirements for the levels on every subcategory should be elaborated and written down carefully to make this method consistent and independent from the assessor. To justify the method of independence, a Round Robin test should be performed. This test can show whether the same result will be the outcome if more than 10 experts would assess the subcategories.

The selection of interviewees was based on their function in the building industry and how likely they are to use the procurement tool. The list of interview participants can be expanded, with more than three participants in each function at least. Furthermore, remanufactures, and parties that are working in the recycling industry have not been interviewed and more private project developers could be interviewed. This is relevant because of the many procurement strategies and ways of project announcements. For further research, it is thus recommended to look into these strategies to know in what situations the concept can work.

For this thesis mid-rise buildings has been chosen as the scope. High-rise buildings ask for more severe requirements of the façade in terms of fire, climate, wind forces, and construction techniques. The damp open façade systems, which are described in the thesis, are not commonly used in high-rise projects. To make this tool fit for high-rise projects, stricter regulations have to be taken into account, and thus, for now, the tool should not be used for high-rise projects.

The tool is now only focussing on facades as a starting point. The tool should be expanded with different modules adding installations and construction, to make it usable for a whole building.

The tool should be updated regularly to keep asking relevant questions. A subcategory may need to be added or removed in the future based on new insights.

7.2 Conclusion

To conclude on the work, the sub questions are answered after which the main research question can be answered.

§7.1.1 **Question 1)**
How is circularity defined in the built environment?

In the current, linear built environment, the consuming, linear take-make-dispose model is dominant. Raw materials are mined and processed into products that, after usage, will turn into waste. To counteract this waste production, new models have been created. Under which, the circular economy that tries to restore the pressure on earth's life-supporting systems. One of the objectives of the circular economy is to close the material cycle. This can be achieved by stopping the need to mine these raw materials and streamlining the mined materials to prevent them from turning into waste. The other factor is to reduce the impact on natural capital. This impact is caused by turning materials into products. Resources such as fresh water and energy need to be spent, and all sorts of (undesirable) by-products may get released into the environment.

The way in which value is created and preserved must thus become more sustainable, and for this to happen, business models have to change along as the definition of the Ellen Mac Arthur foundation suggests. A minimal environmental impact can be achieved by designing responsibly. Starting at the choice of material used for the building products, design for longer and more potential life cycles of the products and materials, and minimise the embodied energy by the resources spent during this processing of the materials.

During the building's lifetime, maintenance of the products is necessary to maximise the building products' life span. Furthermore, the environmental impact needs to be minimised. There are many ways to achieve this among by designing the façade for high-energy performances and designing for reverse-logistics.

§7.1.2 **Question 2)**

What are the requirements of the façade to prevent obsolescence?

Obsolescence can lead to earlier than planned demolition of a building. From a sustainable perspective, renovating is better than demolishing and constructing new.

The location of the building influences the material durability of the facade by the salinity in the air, sun orientation, the distance and intensity of roads and traffic. Applying suitable materials is thus of importance to maximise the life of the façade.
The building envelope bears many functions to protect the interior of the exterior environment like wind load, rain, and snow. The construction of the building does also influences the flexibility of the facade.

The facade is the part of the building that needs to connect the interior with the exterior, providing light, ventilation, and view. To prevent obsolescence, the facade needs to fulfil these functonal aspects.

Obsolescence is however not only caused by technical degradation, but exogenous factors can also play a huge role. When a building can adapt to regulations, and the wishes of future users, demolition of can be prevented. Regular maintenance is important to prevent physical and behavioral obsolescence from aspects caused either by the building itself or by influences of the environment.

§7.1.3 **Question 3)**

What are the potential bottlenecks of the circular economy in the residential building sector to overcome?

What are the potential bottlenecks of the circular economy in the residential building sector to overcome? The ambition of the Netherlands is to realise a circular economy before 2050, while the intermediate goal for 2030 is to use 50% or less primary raw materials. But even though the goal is known, there is still a lack of knowledge and experience in the market about circularity. As each sector is using an own definition of the circular economy, this can lead to greenwashing.

Many new approaches in all sectors are needed to accomplish a circular economy. To stimulate the use of secondary products and materials, innovative techniques need to be developed. Material passports and artificial intelligence can help to define material flows between sectors. and help to keep the materials inside Europe.

Start-ups often suffer from a lack of access to inspections due to costs. Circular business models often struggle to succeed as private investors and bankers evaluate the risk unnecessarily high.

This lack of knowledge and experience holds back the transition towards a circular economy as linear choices are still cheaper.
Procurement can be utilised as an accelerator of the circular economy where circular ambitions are translated into the requirements of the project. However, procurement is still mainly about achieving the best price-quality ratio. However, most project developers lack the in-house knowledge of clarifying their circular aim in tendering, which results that the parties involved will only steer on reduction of the energy consumption rather than going fully circular when sustainability is included as an award criterion.

The main environmental requirement is based on the CO_2-Performance scale ("CO_2-prestatieladder"). and the newest tools are the BREEAM-NL MAT 5 (materialisation) and MAT 8 (building flexibility). However, they but do not provide in-depth insight into all circularity aspects.
Therefore a different and more elaborated method should be used, which leads to the research question of the thesis:

§7.1.4 **Research Question:**

"In what way can a procurement method stimulate the implementation of circular façade systems in mid-rise residential buildings in the Netherlands."

Procurement has a significant influence on the initiation of circularity in the project. The more circular projects are asked on the market, the more advisers, contractors and suppliers have to implement them into their design proposal. However, project developers lack the knowledge and experience in circular tendering, which results that the parties involved will only steer on reduction of the energy consumption rather than going fully circular when sustainability is included as an award criterion. The thesis proposes therefore on this research question the circular procurement tool, that all key- parties can use during the procurement. The tool is meant to enhances collaboration and offers the opportunity to address the responsibility of each party.

The tool can help public authorities such as the municipality set circular binding conditions for the project in exchange to hand over land to the project developer. In this way, the municipality will be able to initiate and demand the circular ambition for the project. Most project developers lack the in-house knowledge of clarifying their circular aim in tendering, the tool should help make the practical implications of the circular ambitions of the project developer and municipality explicit. The tool help the parties involved early in the process with the tender's selection procedure.
The tool is based on the circular economy principle and offers a framework to categories the impact on the environ-

ment into three main themes; Reducing the input of raw materials, Streamlining the mate-rial output, and Lowering the pressure on the natural capital. These main themes can be split up into categories and subcategories to further specify the circular ambition. This framework allows assessing and justifying the performance of parties and can categorise and assess the individual benefits of the circular measures in facade systems and products in a systematic way. The tool takes into account the circular strategies , the requirements to prevent obsolescence of facades and the bottlenecks.

Firstly, the municipality should decide which of the three main categories should be focused on by determining weighting factors based on the levels of the already existing 'Ambitieweb'.
Secondly, the project developer can further divide weighting factors over the various (sub)categories. These weighting factors will be translated into points that will form the circular criteria of the tender. The parties and façade systems can be assessed in these subcategories and achieve points accordingly. The results will be shown in a radar chart to provide an overview of all tenders and façade products and systems, making it possible to compare and evaluate them on the initial ambition. The tool can then be used to keep track of the circularity ambition during the project. The (facade) contrac-tor and all suppliers need to provide the tool from data about the product, and their services through-out the design process. This makes monitoring for necessary adjustments during the project possible. And help the key parties to attain a better understanding of their design choices concerning the impact on the environment. And at the end, evaluation on the ambition is possible.

Validation:
To validate the tool, the method has been tested on the product and building system level. The results clarify how the products and systems are circular and in what circular aspects improvement is possible. The tool is evaluated through a deep renovation project at location Reigersbos, Amsterdam, where circular facades will be applied on midrise residential buildings that have been built in 1984. The current process of setting circular ambitions for the project has been compared with the same process and the tool's help. In this case study project, a selection procedure has taken place to unify different parties that were willing to work together and are able to enhance the circularity of the project. Such a process is complex and requires the necessary investigations and engagement of all the parties such as architects, constructors, and suppliers already in an early phase of the procurement. The systematic approach of the tool can help make to make future processes less time-consuming.

Interviews with field experts have been conducted for feedback on the tool in terms of functionality. It is said that the tool supports the design process and can lead to responsible and knowledgeable decisions rather than replacing the design process to generate generic solutions. For the (facade) contractor, the tool offers an easy-view to determine if their services would fit the project requirements and to see if changes in the system's design or supply chain are needed. Furthermore, from the supplier's perspective, the tool provides the opportunity to improve their products to the market's demands. Nowadays, it is not always known which sustainable innovation should be prioritised, which leads to a high amount of inefficient product development.

7.3 Recommendation

Realisation of the circular procurement tool for facades of mid-rise buildings will depend on follow-up research in various domains. The recommendation is divided into two aspects, theoretical and practical recommendations.

The requirements for the levels on every subcategory should be elaborated and written down carefully to make this method consistent and independent from the assessor. To justify the method of independence, a Round Robin test should be performed. This test can show whether the same results will be achieved if more than 10 experts would assess the same project.

It is recommended to carry out a sensitivity analysis to set the score of the weighting factor for the subcategories. For now, each subcategory is weighed the same (factor 1) but some will be of more importance than others for the circular economy. A proposal is given in Appendix B but needs elaboration. To know whether or not this is method would roughly work running the tool on various normal and some extreme examples for a sensitivity analysis provides insight into the influence of the distribution of the scores.

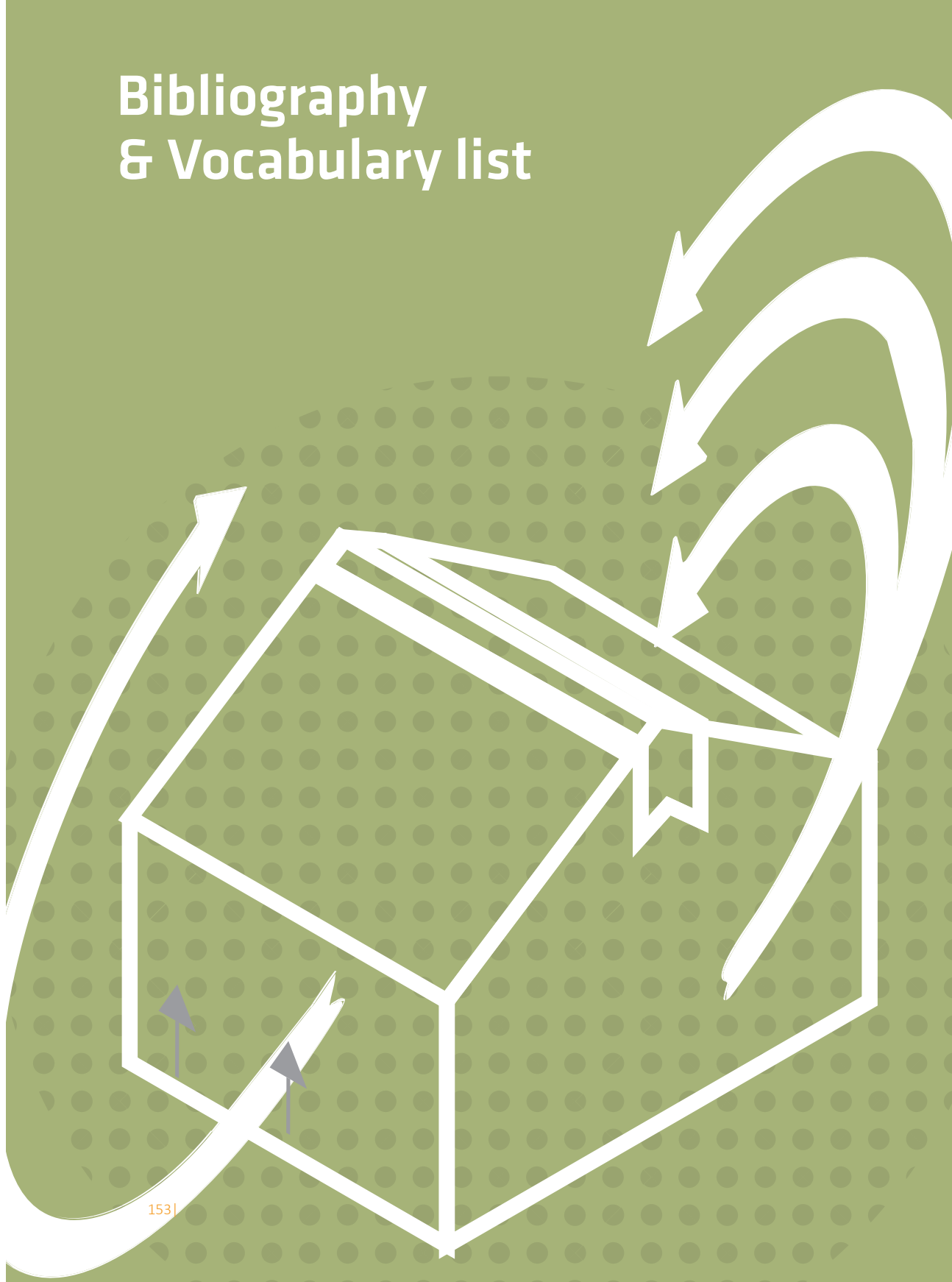
It is recommended to conduct a test with a combination of multiple building products to form a system. When multiple façade panels, IGU's and window frames are combined, the tool should take into account the mass percentages of each product. Once the requirements for each level are described, a certain level can be determined based on the percentage of each product, generated by the tool for each question and subcategory.

§7.3.1 Practical recommendations

It would be interesting to test the procurement tool on tenders to understand the a viable ambition level. When this ambition is set too high, the project will not be feasible, while setting the ambition too low, the full potential for a circular project will not be achieved. The process of this learning process might be comparable to the BENG requirements, starting with a low EPC value, and in time, when the market is familiar and ready for it the requirements can gradually become more drastic.

The tool's next development could be that once a whole analysis on a product with this tool is executed, the results could be stored to be used again in a different tender. The results then should be stored in a public national database accessible for the parties upfront, such as architects or contractors. In this way, it becomes possible to search in this product database and filter on the preferred circular aspects to choose the best suitable products already in an early design stage which may lead to the stimulation of bottom-up initiatives.

Bibliography & Vocabulary list



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Vocabulary list

A

Accessibility of the elements
The ease of reaching the product or elements in the facade. This applies not only for ease during installation of the facade but mainly regarding the ease of maintenance, repair and replacement of the façade. Key elements for this category are: connection types, hierarchy, independency and interfaces.

Accessibility of the façade in general
This aspect is related to the possibility of (dis)assembly of the façade. It also implies the dimensions of the product with respect to carrying of the product 'moveability'. When little space at the project location is available, separation of materials should be possible in an external separation facility where weather conditions do not play a factor like a Hub. qualitatively stable, lightweight and modular elements can improve on the accessibility of the façade in general and the width of galleries or balconies as well.

Air purifying
Includes all techniques or materials that can remove pollutants from the air. Examples are the use of plants, or titanium dioxide as an active ingredient in paint and building materials. It will reduce the air pollution

Architectural influence
Most circular business models will imply a long-term connection with the product and the architect could become more of a recurring "circular"-architects (campagne, 2020).Collaboration in project teams and insight in products of chain partners will probably become more important and interdisciplinary thinking is required for this. The architect has the skill to design buildings that mingles within the environment whereby it adds more value and quality to the location and thus reduces the chance of obsolescence in the future.

B

BENG: Bijna Energieneutrale gebouwen
For all new construction, both residential and non-residential, the permit applications must meet the requirements for Nearly Energy Neutral Buildings (BENG) from 1 January 2021. The requirements have their origin from the Energy Agreement for sustainable growth and from the European Energy Performance of Buildings Directive (EPBD) ((Rijksdiens voor Ondernemend Nederland, 2021).

Biobased materials
Biobased materials are in essence renewable materials so when used in combination with a long enough service life, depletion of raw materials can be prevented (Durmisevic, Beurskens, Adrosevic, & Westerdijk, 2017).Examples of biobased materials other than wood are bamboo or flax for insulation material. Sandwich panels can among other materials be made out hay, grass, tomato plants, hemp and algae.
Furthermore there are also biobased

plastics that are also compostable such as PLA, PHA, PBS.

Building Information Modeling(BIM)
Intelligent 3D model-based digitalisation process that helps architecture, engineering, and construction (AEC) professionals move towards more collaborative, automated ways of working throughout the project lifecycle.

C

Cascading
Refers to diversifying reuse of materials through other applications and states downcycling (form of recycling) applicable to the biocycle (Ellen Macarthur foundation, 2015).

C2C (cradle to cradle)
Certification on products that are assessed for environmental and social performance across five sustainability categories: material health, material reuse, renewable energy and carbon management, water stewardship, and social fairness. A product is assigned an achievement level (Basic, Bronze, Silver, Gold, Platinum) for each category. A product's lowest category achievement also represents its overall certification level. The standard encourages continuous improvement over time by awarding certification on the basis of ascending levels of achievement and requiring certification renewal every two years. (Cradle to cradle products innovation institute, 2021)

Closing material cycles:
This is particularly focussed on the technical cycle of the Ellen Mc Arthur Butterfly diagram. Which is about Maintain. re-use, remanufacture, recycling and at last disposal. Closing the material cycle goes beyond the building sector only as a market for used products. It also implies materials to stay in Europe in different industries. Examples of aspects are retrieving materials back to the original manufacturer of the element to be used again or bundled together for any form of recovery.

Contribution to biodiversity
'ecosystems: To contribute to the diversity of plants and animals we can keep balance of the living environment this is called biodiversity. Another point contributing to this topic is to eliminate light pollutions to avoid hindrance to animals.

Contribution to water
Buffering rain water to help with climate adaptation. An example is with the design of the facade or with vegetation

Creation of jobs in the area
This topic is related to creating of new job opportunities for the people in the area working on an aspect of the facades. An example is the municipality of Amsterdam that has the ambition to create more jobs for the residents in the area of Amsterdam Zuid-Oost. It requires however a large scale project that will ensure jobs for years.

D

Demount ability
The ability to disassemble the product at the end of life. It focusses among other things on the separation possibility of elements and materials. Demountability is necessary for the circular strategies such as re-use, repurpose etcetera

Design for adaptability
is a design methodology to produce dynamic adaptable systems that allow users to have more influence on the design of their buildings. Adaptability of use over time can be integrated by allowing flexibility in the design plan and modularity. This is an important factor when it comes to prevent obsolesce of the building. Apart of the design, the required information for transformation should always be available when needed. Table V1 shows the themes of adaptability in more detail.

Frequency of change	Description	What to achieve with the facade	How to achieve
High Yearly **Adjustable**	The capability of the building to change of tasks. This can be achieved with non-fixed elements such as plug and play elements or stackable elements, but also detachable connections and operable elements where the user is in control.	Change in sunshading	Plug and play elements User control Non-fixed objects Detachable connections Operable elements
Versatile	The ability of a building to change of space. Examples are movable walls, variety of room sizes, wide corridor widths, frame constructions but also flexible ducts and excess service points.	Change of facade element configuration Change of facade subsystem configuration	Movable divisions Variety of room sizes Frame in construction Flexible ducts Excess service points
Refitable	Connected to the change of performance of the building. A way of achieving this is with standard shapes, dry connections, interchangeable components.	Biodiversity — Vegetation elements Green facade components Air purifier (TiO_2) Integral air/water collection Fauna habitat Climate regulation — Outside suscreen Inside suncreen Sun control in the IGU Ventilation Climate facade component Aesthetics change — Dynamic facade components	Dry connections Standard shapes Interchangeable components Many access points Digital platform
Convertible	The ability of a building to change the function. With a large floor-to floor dimensions buildings, spaces can be transformed easily to the wishes of the user with the use of dropped ceilings, raised floors. Furthermore, simplicity and multi-functional spaces are also key factors.	Window area +/- Doors +/-	Raised floors Dropped ceilings Simplicity &legibility Excess service capacity
Scalable	The ability of the building to change of size. Modularity, excess space, dividable rooms, dividable and joinable rooms are examples of this.	Increase the building size — Entire facade to the outside Part of the facade to the outside Addition of a storey Decrease the building size — Entire facade to the inside Removal of a storey Transformation of the space — Part of the facade to the inside-loggia Balcony/corridor Changing balconies, galleries into rooms	Local materials Known techniques Modular units Structural reduncancy Extra space on the plot Dividable rooms
Rarely 75 years **Movable**	Change of location. Deconstruct able structures, easy connections, low-weight or adequate sizes are key aspects of it.It can also imply reuse of the building in other buildings.	Move the total building Move all facade elements to another structure Reuse of the facade elements Reuse of the facade system, subsystems or components	Component scale Collapsable Easy connections Kit-of-parts Component weight Stackable (easy stored)

Table V1: Design for Adaptability with its subcategories.

Design For Disassembly: Approach to design complete buildings or building elements that are easy to disassemble in individual components or elements which allow for separation of materials to enhance the component to be reused, reassembled or eventually recycled into new products of similar or higher quality (Jensen & Sommer, Building a circular future, 2016) .

Duurzaamheidsprestatie gebouw (DPG)
A developed method that expresses the total sustainability performance of a building in a single indicator.

E

Embodied energy: Embodied energy is the total primary energy in kWh consumed through the life cycle of a building. It includes the energy expended for raw material extraction, the manufacturing of materials, and transportation to the construction site; the building construction, maintenance, repair, and replacement of building components during operation; and the demolition, transportation of materials, and their end-of-life management but excludes the operational energy consumed within the building (Moncaster & Symons, 2013).

Economically Most Advantageous Tender (EMAT) Procurement type where other criteria, in addition to price, can be taken into account.

Energieprestatienorm voor gebouwen EPG is a normed method to determine the energy performance of a building.

Expected life span
the 'n' in n-life refers to the amount of life times of the product/element without excessive maintenance or repair.

Exported energy
Excess energy that can be exported to the grid or another form of energy that others can make use of which is either during life time of the building or during production.
Building products can also store energy in them for example electricity or with phase changing materials that absorb and release heat. Furthermore, a façade can also produce energy.

G

Green Deal circulair inkopen (GDCI) is an initiative where public and private parties work together to bundle their knowledge and boost the circular economy on procurement policy.

I

Input of raw materials
Reduction of input of raw materials could be achieved with an optimised design and leaving out unnecessary volumes. Rare material , non-renewable materials and the (harmful) impact on the environment from of toxic materials and emissions.

Insulation level
The required insulation level higher than the building decree.
It is applicable to the R-value of opaque parts of the building and to the U-value for windows.Where better insulated buildings waste less energy on a comfortable interior.

K

Knowledge transfer:
Knowledge improvement, from one or more stakeholders through experience of other stakeholders. This could be achieved through monitoring of the product or remanufacturing with either the original manufacturer or contracted remanufacture. But it has also to do with the choice of a building team or traditional way of designing and the collaboration between parties.

L

Life Cycle Assessments(LCA)
Life Cycle Assessment (LCA), a method to analyse the environmental impacts during the whole life of a product.

M

Modularity
Re-use can be stimulated when a form of standardization is used in the design. Standard of dimensions, connections or product edges are ways of making use of standardization. The same applies for modularity. it could be by using for the main element certain dimensions in this way re-use will be stimulated.
It would make sense to implement a form of modularity in the design it could be by using for the main element certain dimensions in this way re-use will be stimulated.
Specialist technologies should be avoided as this can hinder the replicability of the element when this technology is no longer in use.

Monomaterial separation
Before reusing a component, it is necessary to check its quality. To make this process easier only primary and secondary monomaterials should be used.
A primary monomaterial is a single homogeneous material used in its natural state such as untreated wood. A secondary monomaterial is a mixed material such as concrete, glass or cellulose fibre. An example where checking the quality of a component becomes difficult is in a prefabricated building element where cladding, insulation and the structure are integrated in a single component and thus where different levels of decay can be identified in one single component (Berge, 2000).

MPG MilieuPrestatie Gebouwen
The MPG is an important measure of the sustainability of a building which is required for a planning application (article 5.9 of the building decree). The environmental impact is expressed in environmental costs which are called 'shadow costs'. The result of the MPG has the expression: shadow costs / gross squared meter floor

N

NOM (Nul op de Meter)
Net Zero-energy buildings (NZEB), is a building with zero net energy consumption. This means that the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site.

O

Obsolescence
-Endogenous physical obsolescence: Degradation of the performance of the building caused by the technical design of the building.
-Exogenous physical obsolescence: Degradation of the performance of the building caused by factors from outside the building.
-Endogenous behavioural obsolescence: Degradation of the performance of the building by behavioural factors within or directly related to the building itself.
-Exogenous behavioural obsolescence: Decline of the performance of the building by behavioural effects from outside.

P

Packaging materials
Made from biobased materials or technical materials. In this category the focus is more on the suitability of the material and the way it is used.
When the packaging is created to wrap around and would tear after one use, it would make sense to have the wrapping material created from secondary materials and from renewable materials that have a fast-growing rate e.g. biobased materials other than wood.
Packaging used to carry heavy parts, such as trays could also be made from durable materials.
In that case it is important that these trays will be used more than once and thus have to be retrieved again. In both cases it is important that the materials will be or collected or retrieved again

Prefabrication
Prefabricated building envelope elements allow for less polluting machines on the building site which is favourable for the environment. Prefabricated elements are less prone to mistakes and thus can offer better wind tightness.
Half prefabricated elements are for most parts fabricated in the factory but need a water tight foil wrapped around on site while fully prefabricated systems only need to be assembled on site.

Q

Qv10:
The Qv10 unit indicates how many litres of air per second, per squared meter facade at a pressure difference of 10 Pa flows through the building envelope (dm3 / s per m2) and is measured through seams(the meeting between the glass and the window frame or glazing bead, as well as the meeting between the window frame and the glazing bead.) according to the VMRG.

R

Reduction of greenhouse gas
This concerns all methods of reducing greenhouse gas in the stages before service life. Generating energy that produces no greenhouse gas emissions or reduces air pollution. Diversifying energy supply and reducing dependence on imported fuels Renewable fuels are fuels produced from renewable resources. Examples include: biofuels (for instance vegetable oil used as fuel, ethanol, methanol from clean energy and carbon dioxide or biomass, and biodiesel) and Hydrogen fuel (when produced with renewable processes).

This category also implies innovative ways/ optimal use of energy from the near environment. For instance, using a local heat and power station to heat threatening timber and the use of district heating which can be counted as secondary energy.

Registration and quality control:
This is based on how well the product is documented and can be checked.
Documentation and registration is of more importance to know the location and state of the products know when it comes available for either reuse as closing the cycles through other industries. It can also help to keep materials to stay in the Netherlands or Europe for a continuous end-of-life scrap material

Remanufacturer
There are mainly three types of remanufacturing companies that are categorized based on their relation to the product manufacturer as is explained in (Sundlin, et al., 2016).
Independent remanufacturer (IR)
Contracted reman¬ufacturers (CR)
Original equipment manufacturer (OEM)

Renewable resources
Resources that can be harvested or renewed on regular bases. (Berge, 2000).

Reverse logistics Supply chain where the goods move from the end user back to the seller or manufacturer. It can include components for refurbishing and remanufacturing. The products may be resold or disposed.

S

Secondary materials can either be Recycled or reused materials.
Using secondary materials implies less demand for virgin raw materials
Only post-consumer and material that would otherwise have entered the solid waste stream but in¬stead being recycled are considered as recycled.
Post-consumer material is material that do not longer function for its intended pur¬pose generated by end users such as households or industrial facilities. In practise these are the materials coming from recycling waste.

Service contract
This category is about maximising the potential of service life extension. The inclusion of a service contract stimulates repair and maintenance during service life to extend the life span.
By inclusion of structural redundancy when foreseen, materials and can be saved in the future by an integrated design.

U

Use of fresh water

Water is a renewable resource, but only at the rate that the eco-system allows. The worldwide demand for water has tripled over the last 50 years. Forecasts suggest that more than half of humanity will experience severe water shortages by 2050. The building industry is the second largest water consumer. It is and thus relevant to include water usage in the resource-list required to create materials. Salt-water usage is not a problem as 97% of the water on earth is salt, while accessible fresh water accounts for less than 1%; Most materials use a significant amount of energy in production, most of which comes indirectly or directly from burning fuels. In extracting this fuel, water is used for washing and dust suppression. Water is also used in cooling water cycles, with significant loss through evaporation. Table 1 lists water usage per MJ of delivered energy for electricity, both produced and distributed via a public grid system, and electricity produced industrially (industrial electricity generation is more efficient as the hot gases produced can be used in other processes, whereas they are simply vented in electricity production for the grid). Source: (CES EDUPACK 2021)

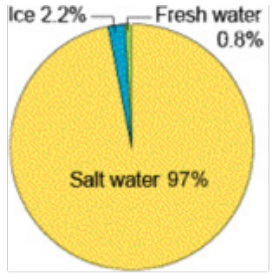

Figure V1: Part of fresh water. CES EDUPACK 2021

- *The water demands of energy*
- *Energy source kg water per MJ*
- *Grid electricity 24*
- *Industrial electricity 11*
- *Energy direct from coal 0.35*
- *Energy direct from oil 0.3*

W

Waste disposed

Regarding waste management.
Output of the company e.g. water pollution and trash for landfill.

Appendix

A | Weighting factor calculations for categories
B |Circular facade systems
C |EPD
D |Timeline of activities
E |Biobased products
F |Mat 8- BREEAM-NL

A

A Weighting factor calculations for categories

In the thesis, each subcategory has a weighting factor of 1. One of the discussion points is that this is not correct. For instance, in the category of secondary materials, reused and recycled content are both worth the same, while from a material perspective, recycling is less efficient, and new material often has to be added to the recycling batch. This part of the Appendix will contain a concept proposal on how to better suiting weighting factor on the assessment subcategories based on the framework of the circular economy and is derived from the perspective of a building product,

§A.1.1 **The relation between the subcategories and the circular framework**

The framework of the circular economy is coupled with the product life stages(-figure A2). The subcategories are placed in this framework (Figure A.3.) and are shown either in red or in green colours, indicating a positive or negative influence on the environmental impact that the product causes over its life cycle stages. (mainly from the cradle to the grave). The subcategories where time is of importance in the life-span are also indicated with the time reference. The following formula defines the product circularity factor:

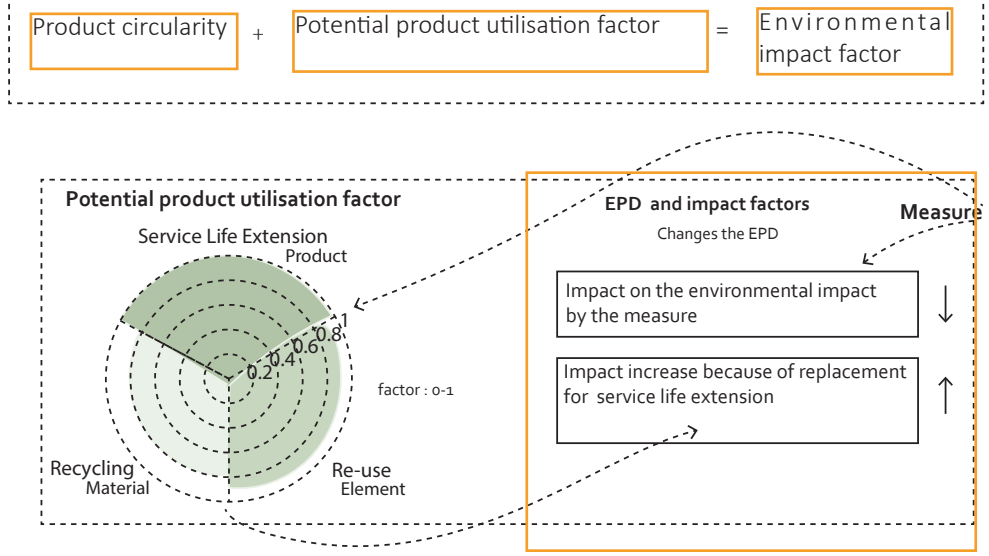

Figure A.1: Product circularity =Potential product+ Environmental impact factor. Own figure

The first factor in the formula is the potential product utilisation factor, which determines how well the chosen materials inside the product can be used to their fullest potential. It is based on the definition of The Ellen MacArthur foundation on circularity "The aim to keep components and materials at their highest utility value at all times". This implies that the value of the components and materials should go beyond the first service life.

In order to extend the service life of a product, certain measures need to be taken to make circular strategies such as service life extension, reuse, refurbish, remanufacture possible. The second factor is the environmental impact factor and formulates the impact the product has on the environment, including the potential service life extension. The following principles are used for the framework regarding the environmental impact factor. (Based on the advice of. Dr .ir. M.C.M. Bakker)

A product may first be reused a few times and then be recycled, which is most likely for the valuable metals in the product. Other materials in the product may be lost earlier. Also, renewable materials are valuable; they took resources to make them. So they also should stay in circulation as long as possible. The circular economy is all about preserving the embedded energy and other invested resources as long as possible. A product lifespan of 25 years is better than a product that can be reused or recycled five times with a 5-year lifespan. Because it arguably takes more resources to make a product fit for purpose again or recycle it than to extend life (in the first -life). Waste collection, transport and processing is part of the reuse or recycling cycle.

1)Virgin material consumption (V)

- Renewable better than scarce (like metals) : Farming better than Mining.
- Scarcity factor (varies per country/ location)
- Resources spent to make it fit for production

  Use of fresh water,

  Energy,

  Other materials
- Machines needed
- Grow- back time of renewables should be shorter than the life span of the product

2)Production and product (P)

- Recycled materials better than virgin materials
- Resources spent to produce it (water, energy, other materials)
- Durability (25 year lifespan to End-of-Life is much better than 5 year)
- Integrating adaptability in the façade product is important to prevent obsolescence of the building.
- Scalable, convertible, refitable , versatile and adjustable are respectively ranked to the usability of time and difficulty to apply it in the design.
- Registration and quality control will take place in this stage.

3)Life-span and value extension (L)

- Maintenance and repair better option than re-use.
- How often needs the product to be repaired/ refurbished?
- A service contract will lead to a longer service life.
- Accessibility and reachability of the product and elements define the possibility and ease of maintenance, repair, refurbishment.
- Value generation for the environment of humanity and biosphere is important during use of the product.
- Architectural influence is mainly important to build an aesthetically pleasing environment.
- The living circumstances are partly also affected by the qualities of the chosen BENG related factors, i.e. a better insulated building keeps the inside on a comfortable condition. However, the Building decree already determines the mandatory minimal level. Values better than this, help with energy reduction.
- Energy generation and storage also contributes to less extern energy demand.
- Prefabricated contributes to achieve a consequent quality level

4)Reuse (RU)

- Better option than Recycling
- How many times can/will the product be reused (N reuse cycles)?
- Resources spent per cycle to comply with new market demands (water, energy, other materials)
- Better option than Recycling
- How many times can/will the product be reused (N reuse cycles)?
- Resources spent per cycle to comply with new market demands (water, energy, other materials)

5)Recycling (RC)

- Material fraction lost (penalty factor: not everything can/will be recycled per cycle)
- How many times can/will 1kg of this material be recycled (N recycling cycles)
- Resources spent per cycle to comply with new market demands (water, energy, other materials)

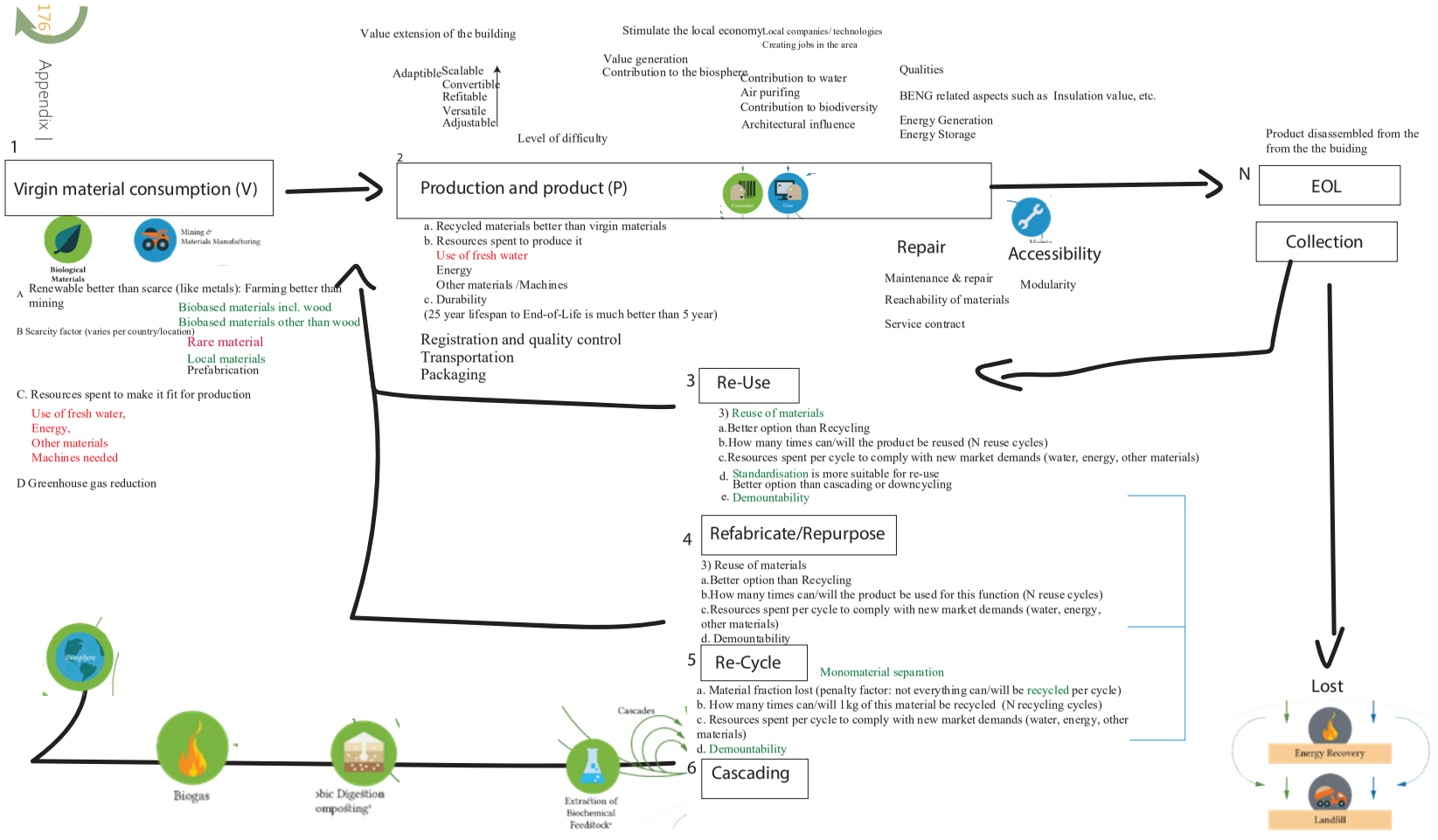

Figure A.2: Butterfly diagram of the Ellen MacArthur foundation adapted to life stages of a product.

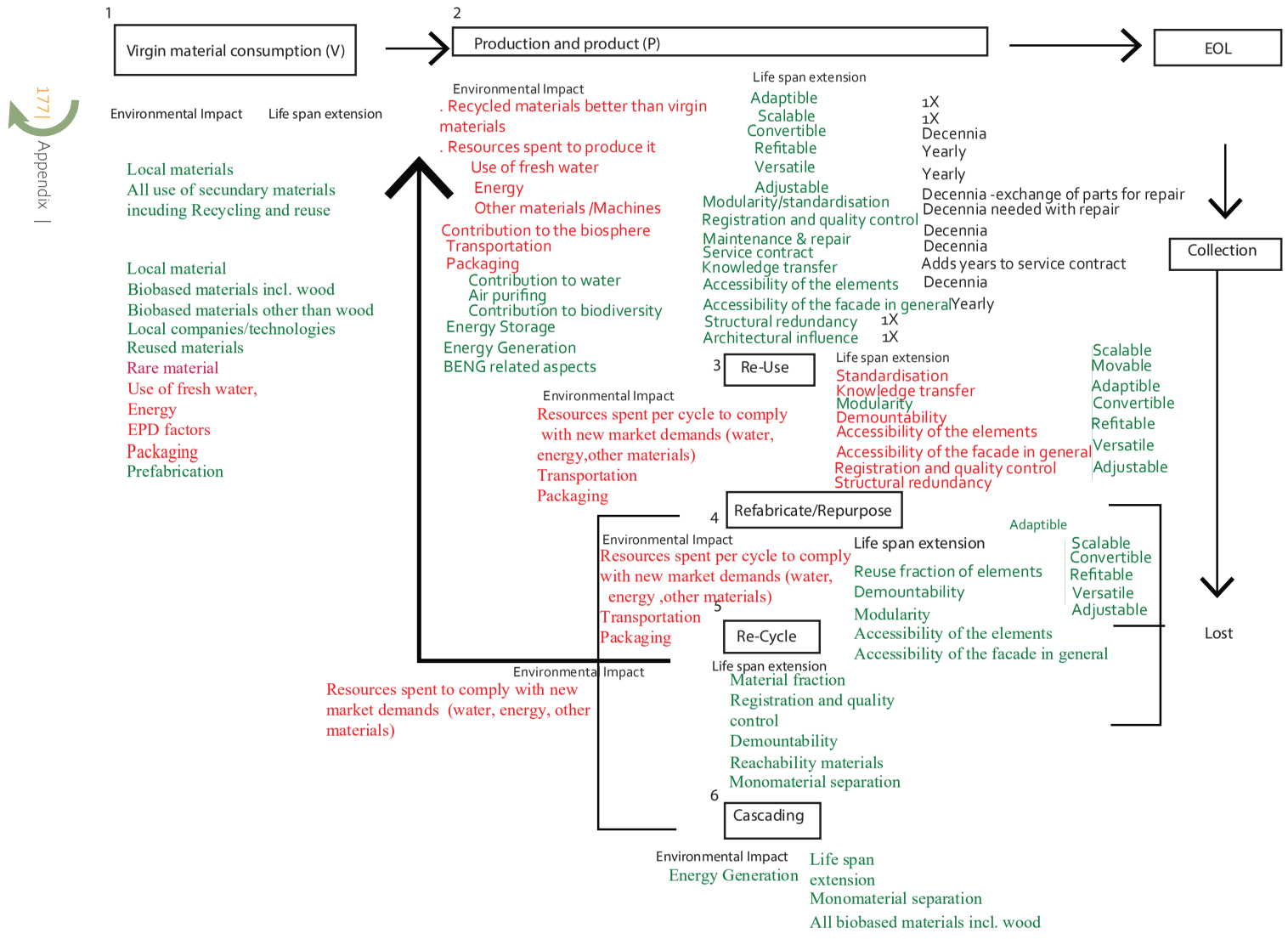

Figure A.3: Using the work of the Ellen MacArthur foundation as a framework.

§A.1.2 **Environmental impact factor**

The environmental impact factor of the product after N-life is defined by two aspects: The environmental impact and time. The relation is shown in figure A.4 In this graph, a linear reference product is displayed as a black line to show the impact over time. The line starts off at time To, which is the environmental impact after the completion of a building project. At To, the aspects Virgin material consumption (V) and Production and product (P) are taken into account, of which the results are shown in an LCA or EPD(figure A.15). At Time L1, the first life span has been reached, and another façade will be assembled. The result of the environmental impact at the end-of-life span L2 is thus the summation of both products (including transportation at the end of life) and all and the materials that will be lost.

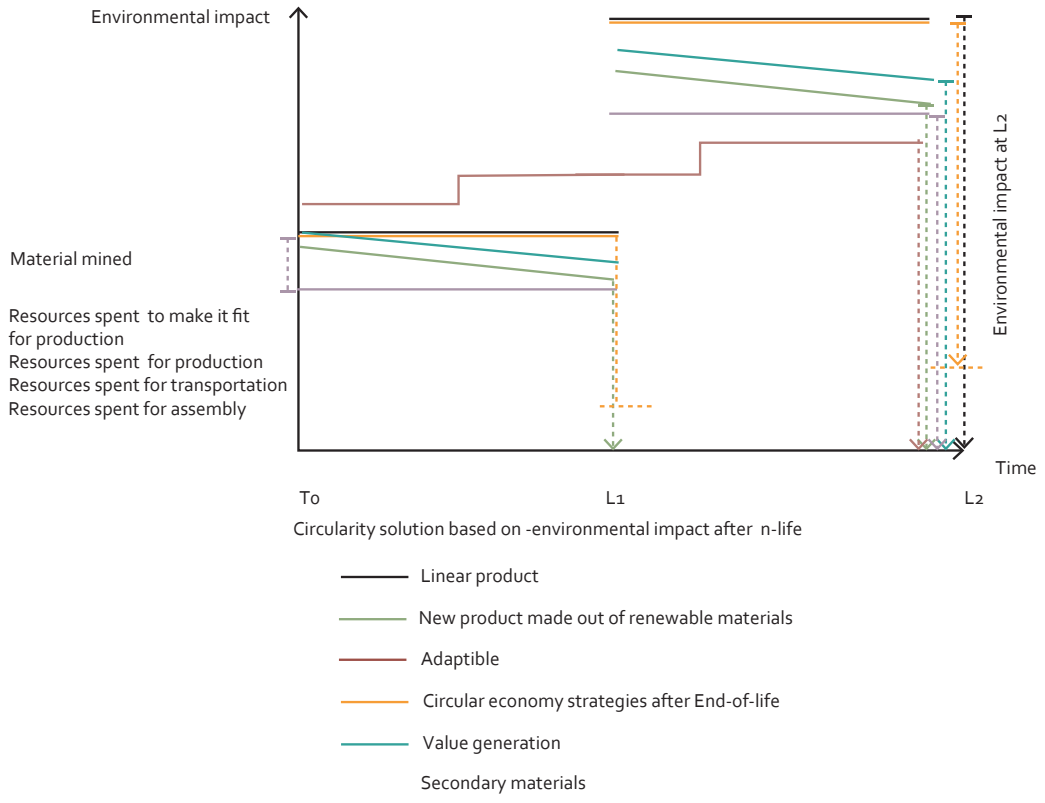

Figure A.4*:* Environmental impact factor. Own source

Renewable materials

Shown by the green line. This line in the graph shows the impact of a façade system made out of renewable materials. As can be seen, the impact Io at the start is lower than the Io of the linear product. This is because no scarce material is being mined. Over time, this value will decrease when new renewable material will grow back and thus, the faster the product's growth rate, the faster the environmental impact will reduce at the end of the second end-of-life. (L2) the environmental impact shown by the length of the green arrowed line is thus less than of the reference line.

Adaptability

Represented by the red line, more materials are consumed to include adaptability in the design. However, there is no need to replace the façade at Lo because the façade is able to adapt. This results in a lower environmental impact despite the repair and maintenance times.

Recycling

The yellow line represents recycling. This line follows approximately the reference line. Only at the end-of-life materials will be recovered and thus will save on waste of discarded materials. The length of the yellow dotted arrow-line that represents the environmental impact is thus smaller than a linear product.

Value generation

for the environment of humanity and biosphere is important during the use of the product and is represented by the blue line. It decreases the environmental impact during service life.

Secondary materials

The environmental impact of secondary materials used as building material. The needed resources spent on production is partly eliminated, and less virgin material needs to be mined. The line can be for reused, repurposed, recycled input.

Note:- The figure is only a sketch, and no information can be taken on the slope of the lines. It only explains the first part of figure 3 (also shown below) that the circularity of a product is thus related to the life span (extension) of the materials (time) and environmental impact.

The Environmental impact is also taken into account nowadays and processed in the MPG (figure A.1..4), but by calculating the MPG for the whole building, these environmental impact factors will be calculated to a functional number (BVO) m2 a year where the years depending on the function of the building (reference: 75 years for residential buildings)

However, for a comparison of façade products, it would make more sense to calculate these values over the total kg material used over a time period of the entered service life of the façade (+-40 years or a different number that is filled in). The BVO should not play a role as this is a number to compare different buildings with each other instead of facades. For this reason, the thesis will work with the numbers that can be found in the EPD or NMD instead of the partial MPG results.

The Environmental impact is also taken into account nowadays and processed in the MPG (figure 6) However, With the method of calculating the MPG for the whole building, these environmental impact factors will be calculated to a functional number (BVO) m2 a year where the years depend on the function of the building (reference: 75 years for residential buildings)

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The Influence of the measures have been exploared on product level and the approach is to look at the influence of the measure on either the potential product utilisation factor or EPD impact factors (Figure A5). The Ellen MacAthur foundation describes circularity as "The aim to keep components and materials at their highest utility value at all times" which also implies the value of the components and materials beyond the first service. This is covered by the potential of life cycle expansion whether it is elongating the service life by making remanufacturing and repair possible while the product is still on the facade, re-use on component and element level or on material level. The impact on the environment to produce the product is covered by the environmental impact factor (These can be enclosed by the EPD of products). The two factors factors together could give an indication of the circularity of the product and the measures will influence these . Both will be discussed next.

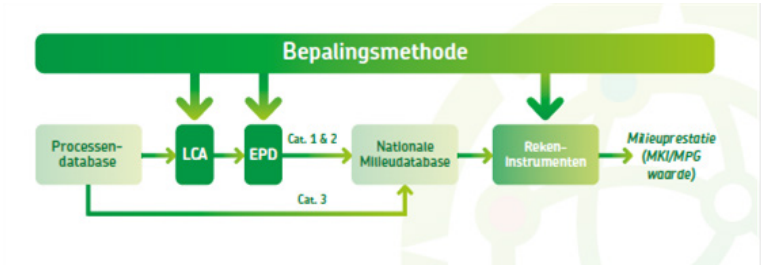


Figure A5: How the EPD is used for the NMD. (Source: milieudatabase.nl)

By applying the measures, the environmental impact will be influenced. These measures are preferably lowering it. This text will explain how the EPD values can be influenced according to the measures and in what aspects it works out.

Secondary materials : Re-use (input)
CO_2; Virgin material consumption: Virgin material and consumption, 100 % reduction on the input corresponding on the % of input.
CO_2;Production: 80 % reduction on the CO_2 on the input corresponding on the % of input.

Embodied energy
Virgin material consumption: Virgin material and consumption, 100 % reduction on the input corresponding on the % of input.
Embodied Energy;Production: 80 % reduction on the CO_2 on the input corresponding on the % of input.

Virgin material
100 % reduction on the input corresponding on the % of input.

All use of secondary materials (recycling)
CO_2; Virgin material consumption: Virgin material and consumption, 100 % reduction on the input corresponding on the % of input.
CO_2;Production: 10 % reduction on the CO_2 on the input corresponding on the % of input.

Water
The industry consumes an increasing amount of fresh water, while forecasts suggest that more than half of humanity experiencing severe water shortages by 2050. Even though water is a renewable source, it is relevant to include water usage in the resource-list required to create materials. Materials use a significant amount of energy for production, most of which comes indirectly or directly from burning fuels. In extracting this fuel, water is used for washing and dust suppression. Water is also used in cooling water cycles, with significant loss through evaporation. Table 1 lists water usage per MJ of delivered energy for electricity, both produced and distributed via a public grid system, and electricity produced industrially (industrial electricity generation is more efficient as the hot gases produced can be used in other processes, whereas they are vented in electricity production for the grid). Source: (CES EDUPACK)Energy

source	kg water per MJ
Grid electricity	24
Industrial electricity	11
Energy direct from coal	0.35
Energy direct from oil	0.3

Figure: Source: (CES EDUPACK)

The use of fresh water can be retrieved from the EPD. When saving on water, 100 % reduction on the input corresponding on the % of input of the material in the product.

Biobased material
Virgin material and consumption: 100 % reduction on the input corresponding on the % of input and it has a linear relation between the minimum life span of and the renewal rate of the resource.

Packaging
CO2; Life span and value: add an extra factor on those who don't mention it and add this 1 % to all
epd values related to gasses and fumes.

(Embodied) Energy
Life span and value: 1% reduction on CO2. Add an extra 1% factor on those who don't have a circular strategy concerning the life span for the packaging.

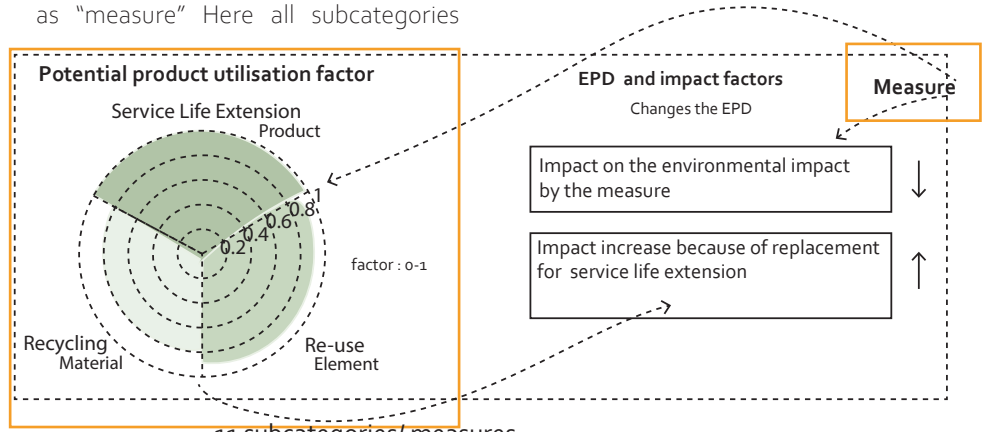
Virgin material
In order to compensate on non-hazardous waste disposed (NHWD), kg/ declared unit. 1% addition. 100 % reduction on the input corresponding on the % of input.

Toxic material
Virgin material : This can be mentioned with the toxicity number of a reference product.

Transportation
CO2; Life span and value: After looking at several EPD of products, transportation is not always taken into account. In case there is no transportation taken into account, the EPD should be corrected by calculating the distance of the individual materials. If the values are not known, a value could be given based on the mined location (globally, European, Benelux or locally) and the sort of transportation and vehicles used.

§A.2.1 Calculating the service life extension factor

The previous paragraph had its focus on the environmental impact factor. This paragraph will show a way to calculate the potential product utilisation factor. The first aim is to keep components at their highest utility value at all times. The best way to do it is in the first life span where the agreements are made about maintenance, and each element will be used for the designed function. The subcategories that influence life extension are in this method defined as "measure" Here all subcategories are weighted the same (weighting factor 1). However, the life span of the product decides which categories are important for a certain time. When a product has a life span of 20 years, only the bottom four factors are important, and thus only those four will be taken into account(Figure A6). When the life span is higher than 30 years, each factor will account for 1/8 (seven factors but the bottom four together will weigh as one). The same counts for 50 years but now all factors play a role.



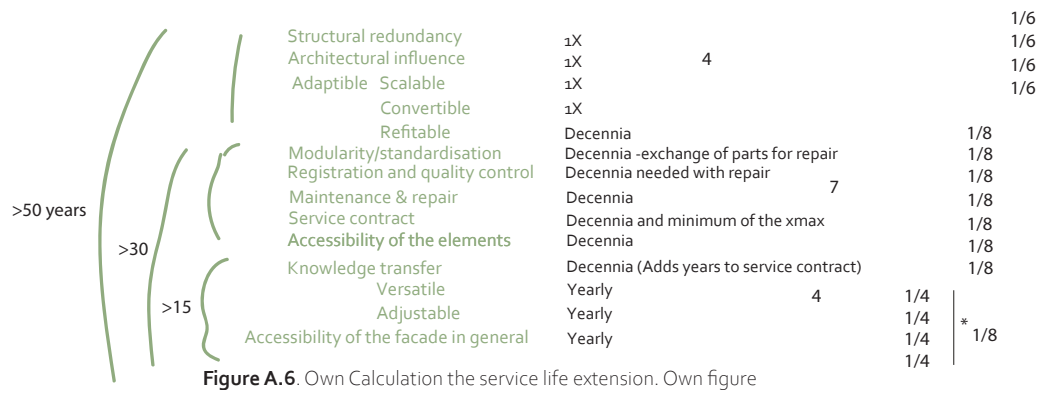
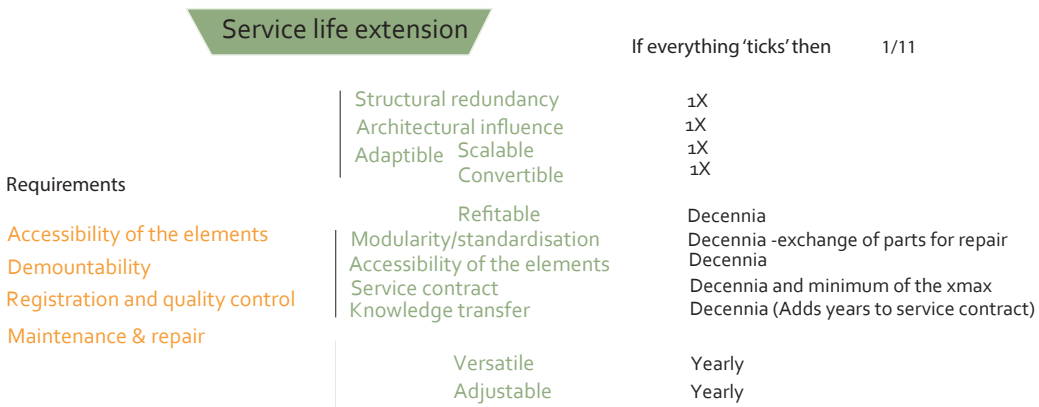


Figure A.6. Own Calculation the service life extension. Own figure

The measures on the service life extension are divided into mandatory measures and optional measures for a composed product. The mandatory measures are needed to be able to repair or replace elements, and it is shown in orange letters. The optional group is shown in green these are measures that will add to the potential of achieving a longer life span(figure A7).



Rules:
The core element has always the governing and thus maximum element life span. Even if other elements have a larger life span.

§A.2.2 Examples of calculations. Service life extension-product

Example 1:

P= product
Ei= Element in the product (The range of i is here 1...amount of different elements in the product)
xi is the life span of the element as provided by the supplier.

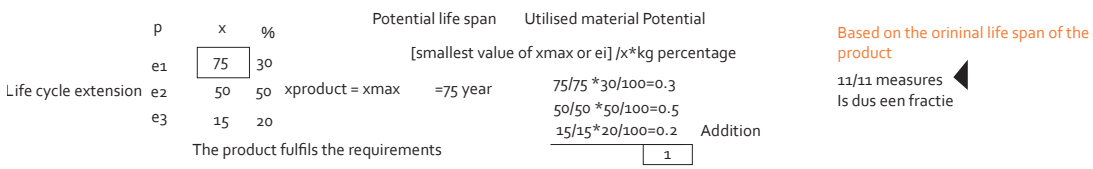


Figure A.7: *Calculating the service life extension.* . Own figure

In this example, the product consists of three elements e1,e2 and e3. The lifespan of element 1= 75 years (and this element at the same time also the core element), element 2 has a life span of 50years, and element 3 has a life span of 15 years. In order for the whole product to reach the 75-year span, there are certain requirements that the product as a whole must fulfil to allow service life extension.

The optional measures will only be used in the calculation. In this case, all 11 will be weighted because the product has a 75 years life span which is higher than 50. When every measure is fully covered (level 3), the change will be 11/11 that all materials will be used to the xmax. In this case, 75 years. The utility of the materials here is 1 as all are used to their fullest potential. In this example, all measures are taken into account as there is no input of the project developer on what is not important for the project.

Example 2: Service life extension-product

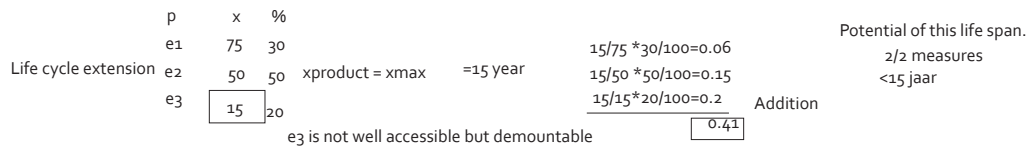


Figure A.8: Calculating the service life extension for a product that is not accessible . Own figure

Again in this example, the product consists of three elements e1,e2 and e3. The lifespan of element 1= 75 years (and this element at the same time also the core element), element 2 has a life span of 50years, and element 3 has a life span of 15 years. However, this time element 3 does not meet the requirement of accessibility and therefore, the whole element needs to be taken off the facade(figure A8). From that point on, it is stated as 're-use' and does not belong to the first life anymore. The product utility factor is 0.41 (when e2 would be accessible and the product would fail one 2 after 50 years, the utility factor would be 0.9 because of the large percentage of e2 material). The chance to achieve this 15 years is 1 (2 of 11 measures need to be checked, so 9 of them will be checked automatically as they are not important*) when both versatile and adjustable meet level 3.

The requirements are different according to the corresponding circular strategies. The same goes for the subcategories that decide for the factor of the potential life extension in years.

§A.2.3 Examples of calculations. Re-use

Requirements

Demountability
Registration and quality control
Movable
Monomaterial separation
Accessibility of the facade in general

chance factor

Standardisation
Knowledge transfer
Modularity
Registration and quality control
Structural redundancy
Adaptible — Convertible, Refitable, Versatile, Adjustable
Modularity/standardisation

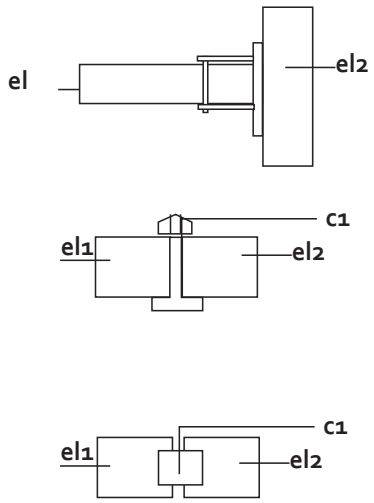


Figure A.10: *Connections possible for re-use* . Own figure

Rules

- In this example, all elements do meet the requirements to allow for re-use (written in orange and the connections can be seen in figure A.10). However, after the first 25 years, the facade will be at its first (N=1) end-of-life.
- In order to re-use an element, or product the minimal remaining life span should be higher than 15 years. It might oherwise not be worth it. (*note. This value could also be different such as 20 years as renovating might take place more often than would be the case nowadays -due to a service contract or because the facade is built from donor material (re-used from a previous building).)

					15	0.75	= percentage that can be re-used (min 15 years working after first re-use)
x	re-use years		kg %			60	jaar = maatgevend
	75	60	0.75	30	60	0.225	0.6
	50	35	0.5	50	35	0.375	
	25	10	0.25	20	10		

- *Re-use utility factor= 0.68*

Figure A.11: Calculation for re-use. Own figure

§A.2.3 Examples of calculations. Re-purpose

- In this example, all elements do meet the requirements to allow for re-use (written in orange and visible in figure A.12). However, after the first 25 years, the facade will be at its first (N=1) end-of-life.
- In order to re-purpose an element, or product the minimal remaining life span should be higher than 15 years. It might oherwise not be worth it. (*note. This value could also be different such as 20 years as renovating might take place more often than would be the case nowadays -due to a service contract or because the facade is built from donor material (re-used from a previous building).) The same is for re-purpose (figure A13).
- This example has a percentage that can be re-used is below a certain threshold value. (for instance <51% but it may be a value determined based on a scientific or practical method.) And therefore the elements that are still in good shape could be used for a different purpose

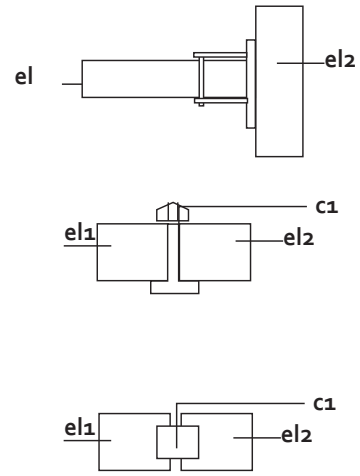


Figure A.12: . Connections possible for re-purpose .Own figure

Re-purpose

Requirements

Demountability
Registration and quality control
Movable
Monomaterial separation

Chance factor

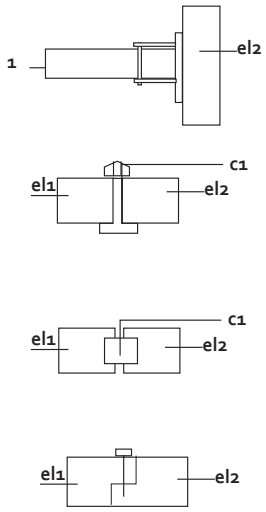
Adaptible — Scalable, Convertible, Refitable, Versatile, Adjustable
Structural redundancy
Registration and quality control
Stakeholder involvement

					15	0.75	= percentage that can be re-used (min 15 years working after first re-use)
x	re-purpose years		kg %			60	jaar = maatgevend
	75	60	0.75	30	60	0.225	0.375
	50	35	0.5	20	35	0.15	
	25	10	0.25	50	10		

- *Re-use utility factor= 0.68*

Figure A.13: *Calculation for re-purpose* . Own figure

§A.2.3 Examples of calculations. Recycling



Recyling/Cascading

Monomaterial separation
Non-toxic materials
Minable materials

Rare materials
Registration and quality control
Service contract
Demountability
Registration and quality control

- Recycling is on the material level. The connection types that allow materials to be recycled can be seen in figure xx. No chemical connection should be used. And the requirements for a material to be recycled can be seen in figureA.14. The calculation is simplified with the material percentage multiplied by the fact of whether or not that element is demountable and satisfies the requirements. Cascading can be seen as a form of recycling but need to be out of biobased materials.

The calculation is simplified with the percentage of biobased material that can be multiplied by the fact of whether or not that element is demountable and satisfies the requirements.

Re-cycle

yes/no

N	Kg%	yes(1)/no (0)		
75	30	1	0.3	0.8
50	50	1	0.5	
15	20	0	0	

Cascading

x(year)	Kg%	yes(1)/no (0)		biobased %
75	30	0	0	0.2
50	50	0	0	
15	20	1	0.2	

Figure A.14: *Top: Connections suitable for recycling.* Bottom:Calculation for recycling. Own figure

§A.3.1 Conclusion

When multiple analyses have been made on several facade products, a more accurate relation between the measures corresponding with the subcategories and the circularity factor may be noticed. On this basis, the weighting value of 1 can be replaced for each subcategory.

Furthermore,the same calculation approach could also be used by the supplier to analyse what measures would have the most circular benefits for the specific product. Based on the analysis, the supplier could decide whether or not the measure is worth the investment.

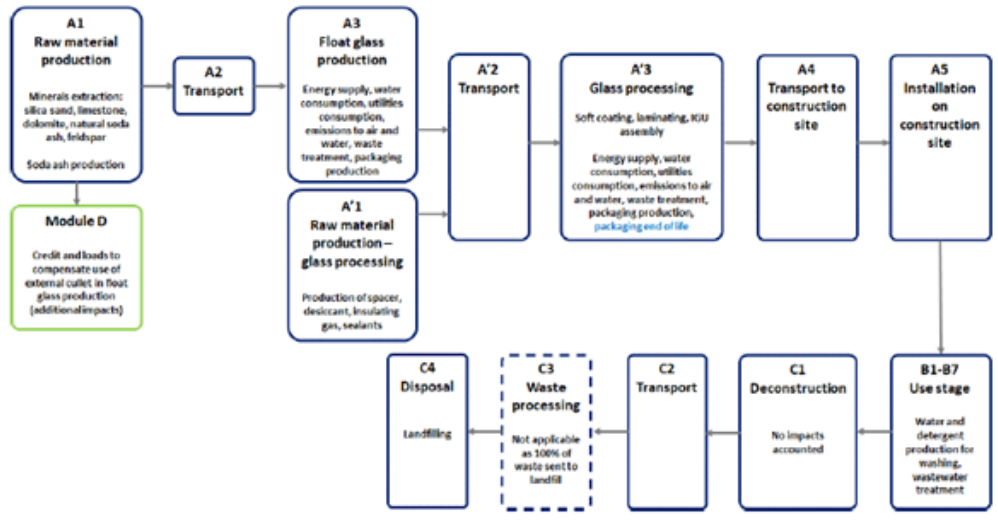


Figure A.15: *indication of which life cycles are taken into account in the EPD. Source:AGC*

B Circular facade systems

For the research, approximately five systems have been looked into to be aware of the differences. The selected systems are either commonly used enclosure system in the Netherlands or other potentially interesting systems for over four storeys. The systems and Ferlem and Strotec have already been covered in the thesis, but details are shown in this part. The following systems will be shown here: Unitised systems, Timber frame construction, SIPS (sipssupply).

§B.1.1 Unitised systems

Unitised systems are ideal for high-rise projects as they can be easily installed on-site. The elements have large dimensions to span from floor to floor. The unitised system provides better working conditions and saves daily transportation as it is prefabricated in the factory. According to (Ebbert, 2010), the unitised system is favourable in the Netherlands.

Unitised panels are entirely assembled in the factory. On-site, they only have to be secured by brackets fixed to the floor slab. The order of fixing from the panels is side by side, then rising floor by floor going upwards. The installation thus is fast and without the need for a scaffold. Commonly used sizes are modules of 1200mm or 1500 mm wide (4 or5 ft), and because of setting up jigs and tools in the factory, it is preferable to create a high level of repetition.

The most commonly used material for this type of facades is aluminium. Therefore it is lightweight and ideal for extrusion, which makes it ideal for a high level of repetition (Reynaers, n.d.). Most parts of the unitised system are dry connected and thus suitable for dismantling. However, the connections of the aluminium baby profiles are rolled into polyamide thermal break thermal, and the corner cleats are riveted. Drilling the rivets out can cause damage or even destroy the aluminium frames. (Vargas, 2019).

In unitised systems, the waterproofing is usually fixed onto the panel before installation and works when placed. An outer line of water defence is provided by rubber-based baffles set on each panel. In this way, they press together and then form a seal. In some cases, an aluminium drip profile is added to the outside of this as the first barrier against the wind but allowing water to drip out again, any water passing through such a profile is stopped in a pressure equalised chamber and drained through the forward baffle. At the back of the joint, there is an air seal which is critical to the performance. Thus, this system's advantage is that the quality is predictable and the high airtightness level.

The transoms and mullions have a thermal break set, but since external air is allowed deep into the joint, thermal calculations are needed to check if the dewpoint falls in the pressure equalised drainage cavity. The insulation value is thus relatively low in this system type.

§B.2.1 Timber frame construction (HSB)

Timber frame construction elements are commonly prefabricated in the factory, where the windows and outer finish are assembled (Figure B.2.2). Timberframe construction elements consist of outer and inner timber panes combined with an internal frame for stability. For insulation, primarily, blankets are used, such as mineral wool. On the interior side, a damp tight foil is installed with a finishing cladding. A damp open foil is placed on the exterior side with the (exterior) cladding in front of it.

HSB elements are usually placed on the floors and connected with steel brackets. However, the connections between the elements and between the floors are wet with the use of sealants.

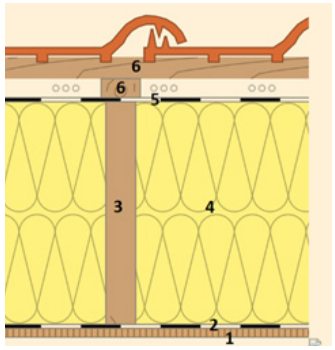
§B.2.2 Advantages:

Relatively cheap
Good thermal performances
Materials (wood) are easy to process and wood is biobased

Disadvantage

- There are a lot of actions needed at the building plot, this could lead to a decrease in accuracy
- The result depends on the quality of installation
- There is just one HSB system known in the Netherlands suitable for highrise
- Wet connections

(Frontwise façade,2020)



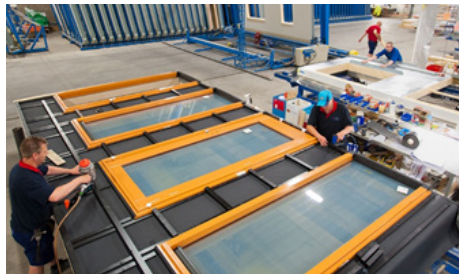
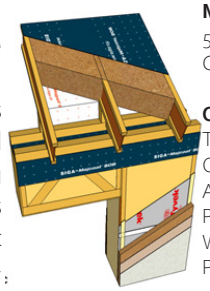


Figure B.2.2: Timber frame construction. Source: https://www.westerveld-nederlof.nl https://www.houtbouwelementen.nl

§B.3.1 Strotec

Strotec works with a similar timber frame construction but is insulated with straw. The prefab elements can be seen as timber frame crates filled with pressed (4 ton) straw(figure B.2.3). By screwing these crates together, a strong whole is created together. It is possible to stack these panels on top of each other without extern construction until three elevations. However, by creating an extern construction, it is possible to go higher. For low-rise buildings, the wall construction can be stacked on site with assembling of the exterior layer and windows. The foil (Tyvek solid) can then be wrapped around quickly. However, total prefab construction is also possible. The Ecococon elements can also be demounted to take the materials apart for the end-of-life scenario (e.g. cascading). Furthermore, this system is also European C2C (cradle to cradle) certificated. The construction itself is vapour open, and the inside of the panels have a loam finish. Together it has a vapour permeability of μ 9,14.

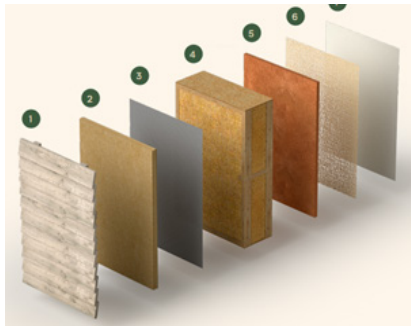
A guarantee of 50 years is assured for the panels when the requirements have been met. One of the requirements is that the panels need to be dryly stored, prevented from being soaked wet during installation, and the construction needs to stay vapour open on the construction's exterior side.



Materials Inside:
5 mm wood fibre strips stapled to wood
Clay plaster (3 layers).

Outside materials
Tyvec, proclima solitex Mento or Isocell Omega light
Air sealing tape SIGA Wigluv 60 mm
Plywood strips
Wood fibre board Steico Protect
Plaster system certified for Wood fibre board.

Increments standard of 5 mm
possible increments of 1 mm



1-Render/ventilated facade
2-Wood fibre board (60-100 mm)
3-Airtight membrane
4-Timber-straw panel (400 mm)
5- Base clay coat (25 mm)
6-Reinforcing mesh
7- Fine clay plaster

Figure B.2.3: Source: Details of the Strotec system. Source: Strotec &Ecocon

§B.4.1 Sips(structural insulated panel system)

SIPS are known for their good insulation properties for low energy consumption. The panels have the construction integrated into the panels, and the whole system is assembled in the factory. The panels are made from OSB3 plates with PU foam sprayed in between for an optimised adhesion but expanded polystyrene EPS, expanded polystyrene with graphite (Neopor-EPS), polyurethane (PUR), or polyisocyanurate (PIR)
can also be used as core. The panels' thickness can vary between 100 mm until 225 mm with respectively the R-value of 2,9 until 7.4 while the measurements of the panels are in line with the standard measurements of the CLS C24 (softwood planks). The panel is vapour open with two OSB3 plates of 15 mm each. A water repellent (but vapour open) foil is needed on the exterior side of the panel. The front and back are meant to be finished with a material of choice. The interior side doesn't need a vapour tight foil in general, but the rooms, as a result, need to be ventilated well. For rooms with a high moisture content, a vapour tight foil on the interior side of the panel and an interior finish cement board is recommended for fire safety. (2 plates of 12,5 mm for 60 min resistance). Electronica can be installed in multiple ways, e.g. by installing an internal framework between the cement board and interior side of the panel or placing cables inside a cement board placing another cement board to cover this. The example and details are from Sipssupply(figure B.4), but more suppliers are available in the Netherlands.

§B.4.2 The advantages of SIPS are

- light weighted
- high insulation
- joints between the panels can cause reduction of quality
- Movements accommodation at higher levels needs to be further investigated (Frontwise facades)
- high accuracy
(Vosmaer, 2020)

Figure B.4: SIPS-System. Source: Sipssupply

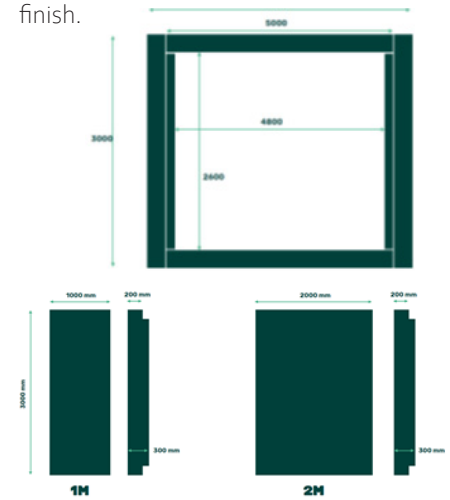
§B.5.1 Ferlem

Sips of Ferlem are vapour tight, comparable to sandwich panels. The connection methods are different from other sips in the connections. (figure B5). The panels with the finish and integrated windows are fully assembled inside the factory, so the house's installation at the location will take just a few days.

The exterior wall is made out of a MgO (magnesium oxide) board attached and filled with recyclable PUR insulation and timber elements for stability. A construction of Ferlem consists of an outer and inner wall with a range of set dimensions. The floor constructions are made out of the same material combination. As the module sizes are set, the production process is made, especially for these sizes and is ideal for mass production.

MGO is a relatively new product in the building industry for the use of façade panel. It is made out of Cementous materials, magnesium oxide, salt, cellulose, water and a handful of other materials. Magnesium oxide boards are highly flame and moisture-resistant. Furthermore, these boards are recyclable, and when grounded, it is nourishing for the soil. However, an artical stated that MgO-boards are not suited as sheathing in exterior facades or any other application where the boards contact a moist climate (Rode, Bunch-Nielsen, Hansen, & Grelk, 2017). Many of these boards caused mould problems on wood and corrosion problems with fasteners from material other than stainless steel in Denmark. Also, the board itself is susceptible to mould growth due to the content of organic material and will be disintegrated over time when exposed to high The panels, as a result, needed to be replaced.

The connection between the foundation/ floor and the walls are with a 'quick-lock system with rails. The wall has a claimed RC value of 9 m2 K/W. The exterior wall's finish is optional and can be of the material of choice, such as aluminium, brickwork, and a wooden finish.



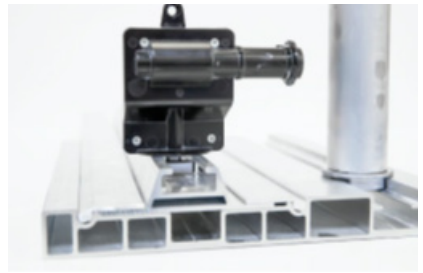


Figure B.5: Ferlem system. Source: Ferlem

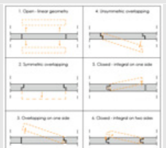
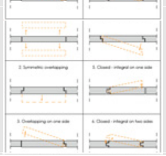
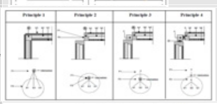
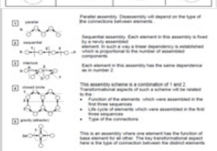
- Rode, C., Bunch-Nielsen, T., Hansen, K. K., & Grelk, B. (2017). Moisture daage with magnesium oxide boards in Danish facade structures. Veldbaek: Elsevier

C Screenshots of the tool

4.1 | Product - Ecocon							
To be filled in by a Supplier-Ecocon							
Element:	e.g. IGU/ insulation/ cladding/ sandwich panel						
Question	Option		Closed answer	element	Answer%	Explanatory answer / Open answer(for now)	Standard of proof	Score (level)
Name of element:	IGU	✓						
Function of element:	Describe the function (such as insulation, structural purpose or .IGU, window frame, etc.)	✓						
What is the quantity of products that are ordered for this project?	560	✓						
Intended life duration (n=1)	30	✓						
How many different elements does this product exist of? (excluding connections/fixations such as glue)	5	✓						
Part 1	inside cladding	✓						
Material part 1	plywood	✓						
Density (kg/m3) of material 1	100 kg/m3	✓						
volume % of the total element	0.005276175	✓						
Life span of this element (n=1)	30	✓						
Part 2		✓						
Material part 1	Luchtdichte folie	✓						
Density (kg/m3) of material 1		✓						
volume % of the total element		✓						
Life span of this element (n=1)		✓						
Part 3	Wood	✓						
Material part 1	Wood C24	✓						
Density (kg/m3) of material 1	100	✓						
volume % of the total element	0.670403917	✓						
Life span of this element (n=1)		✓						
Part 4	Iso	✓						
Material part 1	Isro	✓						
Density (kg/m3) of material 1	110 kg/m3	✓						
volume % of the total element	0.324319868	✓						
Life span of this element (n=1)	30	✓						
Part 5	niks							
Material part 1	Rubber							
Density (kg/m3) of material 1								
volume % of the total element								
Life span of this element (n=1)								
Part 6								
Material part 1	Multiplex							
Density (kg/m3) of material 1								
volume % of the total element								
Life span of this element (n=1)								
81877500	1							

Figure c.1: Categories and subcategories as a result from the product.

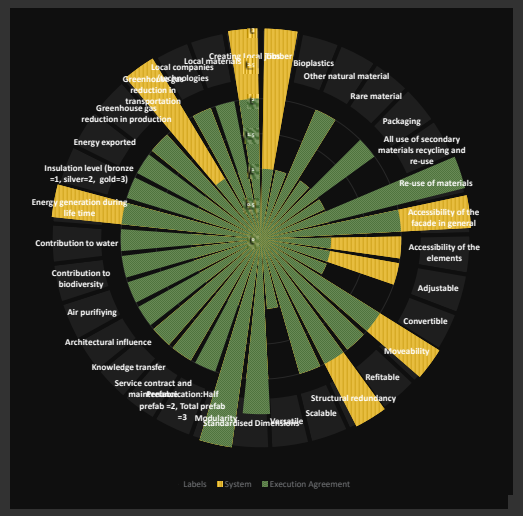
§C.1.1 Suppliers part- example

4.1 | Product - Ecocon												
To be filled in by a Supplier-Ecocon												
Name:				Element:	e.g. IGU/ insulation/ cladding/ sandwich panel							
	Reduce the input of r	Secondary materia	All use of Secondary materials recycling and r	Is there made use of post-consumer, and what is the recycled material input?	Answer in % mass or volume% Describe in mass percentage how much Post-consumer recycled material is used for each component?Post-consumer is materials that do no longer function for their intended	✓	No				yes	1
	Reduce the input of r	Secondary materia	Re-use of materials	Is there made use of reused material input?		✓	No				yes	1
	Reduce the input of r	Reduce the input of raw materials		Describe the innovation of the design in terms of lowering the input of raw materials	No /Yes + explanatory anwswer	✓	Yes	Luchtdichte	99.47%	1,3,4	yes	3
	Reduce the input of r	Biobased material	Timber	Which parts of this product made from Timber?	select the parts	✓	Yes	Wood C24,	100.00%	1,3,4	yes	3
	Reduce the input of r	Biobased material	Bioplastics	Which parts of this product made from bioplastics?	select the parts	✓	Yes	Luchtdichte	32.43%	1,3,4	yes	1
	Reduce the input of r	Biobased material	Other natural materials	Which parts of this product made from biobased materials?	select the parts	✓	Yes	Luchtdichte	67.04%	1,3,4	yes	2
	Reduce the input of r	Monomaterial sep	Monomaterial separation	Can the purity of the materials be checked ?and How pure is the input of the (biobased material)? (Material 1)	No if not applicable / Yes answer in above defined element and the %	✓	Material2		98%	wood -98% also glue	yes	3
	Reduce the input of r	Durability -relation	Durability -relation to 'n'-life	Which elements have hazardous chemicals or toxic inside the materials and the % (volume/mass)		✓	No				yes	1
	Reduce the input of r	Reduce the input c	Rare material	At what stage the toxic/hazardous chemicals come free?		✓	No				yes	1
	Reduce the input of r	Reduce the input c	Rare material	What actions are taken to prevent it from coming free and harm people or the environment?	e.g. IGU could be hazardous at the end of life. However, it will take place in a hub/factory in this way. Th	✓	No			not needed	yes	1
	Reduce the input of r	Durability -relation	Durability -relation to 'n'-life	Which elements out of biobased materials are treated to maximise the lifespan?		✓	N.V.T.	Wood C24,	67.57%		yes	2
	Streaming of the mat	Registration/quali	Registration/quality control	Which certificates does the product have?- multiple possible	Yes/No	✓	Yes			MANY/Fsc	yes	3
	Lower the natural ca	Stimuate the local	Local materials	Where are the minable materials originated from? Answer per region	(No idea, Intercontinental, Europe, Benelux, NL)					EU		1
				Intercontinental				Wood C24	67.04%			3
				Europe		✓	Yes	Wood C24,	100.00%			1
				BeNeLux		✓	Yes	Luchtdichte	67%			2
				Netherlands				plywood, W	100.00%			3
	Lower the natural ca	Stimuate the local	Local materials	Where are the Biobased materials originated from? Answer per region	(No idea, Intercontinental, Europe, Benelux, NL)					EU		1
				Intercontinental		✓		Wood C24,	68%			3
				Europe		✓		Luchtdichte	32.43%			3
				BeNeLux		✓		Stro	32.43%			1
				Netherlands		✓		Luchtdichte	67.04%			2
	Streaming of the mat	Monomaterial sep	Monomaterial separation	Are there coatings used?		✓		Stro	32.43%	not undergone any chemical treatment during the production	yes	1
	Streaming of the mat	Monomaterial sep	Demountability	Are elements designed in such a way that their coatings can be separated from the element after end-of life- for recyclability/reuse etc?		✓	Yes	Rubber, Luc	0.53%			1
		Monomaterial sep	Monomaterial separation	Which elements are made out of primary mono-material?	primary monomaterial /secondary monomaterial/ No	✓	Primar	Wood C24	67.04%			2
		Monomaterial sep	Monomaterial separation	Which elements are made out of secondary mono-material?	primary monomaterial /secondary monomaterial/ No	✓	Primar	Rubber, Wo	67.04%			2
	Lower the natural capita	Lower the natural cap	Lower the natural capital impact(other than mat	Describe the innovation in a design concerning protecting the natural capital (other than materials)	Aspects such as saving emissions and waste into soil, air and water. An example is the carbon footprint.	✓	Yes			Using materials from the area. No chemcal treatment	yes	3
	Lower the natural ca	Waste disposed	Waste disposed	Describe the innovation in the design concerning the prevention of waste	Open answer	✓	No				yes	1
	Streaming of the mat	Demountability	Demountability	Is the product (fully/partially)demountable into separate elements (without causing harm to other elements)?	yes/totally/ partly+percentage/ no	✓	No	Luchtdichte	67.04%	No	yes	2
	Streaming of the mat	Monomaterial sep	Monomaterial separation	Are elements designed in such a way that their material can easily be separated from each other?	No /Yes+ explanatory answer	✓	No	Stro	32.43%		yes	1
	Streaming of the mat	Adaptability	Adaptability	Describe the way how the product /elements of the product are adaptable?	Open answer	✓	No	element			yes	1
	Streaming of the mat	Demountability	Demountability	Are Components and elements designed in such a way that the renewable material can be separated from the minab	No /Yes+ explanatory answer	✓	Yes				yes	3
	Lower the natural ca	Energy generation	Energy generation during life time	Can the facade product generate energy?	Yes/No	✓	Yes	element			yes	3
	Lower the natural ca	Contribution to th	Air purifiying	Are there elements, materials, etc., that contribute to the biosphere during use? (eg. Filtering the air quality)	No /Yes+ explanatory answer	✓	No	element			yes	1
	Streaming of the mat	Adaptability	Scalable	Can the product be adjustable in size depth in the future? (scalable) e.g. In depth, width or height	No/Yes + explanatory answer	✓	Yes	element			yes	3
	Streaming of the mat	Accessibility	Accessibility of the elements	Are the life cycles of the materials/elements in the product the same?	No /Yes + explanatory answer	✓	No			not indicated	yes	1
	Streaming of the mat	Accessibility	Accessibility of the elements	Are those varying life cycles within this product a multiple of each other?	No /Yes + explanatory answer	✓	Yes			not indicated	yes	3
	Streaming of the mat	Accessibility	Accessibility of the elements	Does the core element/material have the longest lifecycle of all elements/material? What is this lifecycle without rem	No /Yes + explanatory answer	✓	Yes			not indicated		3
	Streaming of the mat	Accessibility	Accessibility of the elements								Mean of below	2
	Streaming of the mat	Accessibility		How is the interface of the elements :Which elements use 1? Open-lineair geometry				Wood C24,	67.57%			2
	Streaming of the mat	Accessibility		How is the interface of the elements :Which elements use 2? Open-lineair geometry				Wood C24,	99.47%			3
	Streaming of the mat	Accessibility	Accessibility of the elements	What is the dependency within this product? According to this scheme? (answer with 'No' when there is just 1 eleme			6					1
	Streaming of the mat	Accessibility	Accessibility of the elements	Which of the following assembly sequences are applicable to the design of the product?			4				yes	2
		Rare material	Rare material	Are the non-renewable resources used for the product protected for exposition(to wear or tear)?		✓	Yes	Rubber, Luc	67.04%	n.v.t.	yes	2
	Streaming of the mat	Accessibility	Accessibility of the elements	Is the rule: "use a minimum number of different types of connection and fasteners used " applied For fast assembly	yes/no	✓	Yes				yes	3
	Streaming of the mat	Accessibility	Accessibility of the elements	What is the amount of different type of connection and fasteners?	Amount:	✓	No			2	yes	1
	Streaming of the mat	Accessibility	Accessibility of the elements	What is the total number of elements in the product?	Amount:					12	yes	3
	Lower the natural ca	Reduction of Greer	Greenhouse gas reduction in production	Is this design made use of an intelligent way of energy from the immediate environment?	No /Yes + explanatory anwswerAn example is using excess heat from a factory in the area for heat treat.	✓	Yes	element			yes	3
	Lower the natural ca	Energy generation	Energy exported	Is there excess energy that comes free during production that can be used ?	No /Yes + explanatory answer(if yes,click tick the elements)	✓	Yes	element		No experience yet	yes	1
Production- proce	Lower the natural ca	Greenhouse gas reduction in production		Describe the innovation in production process, concerning protecting the natural capital other than materials	No /Yes + explanatory anwswer	✓	No				yes	1
	Lower the natural ca	Streaming of the n	Waste disposed	Describe the innovation in the production process concerning protecting the natural capital other than materials	No /Yes + explanatory anwswer	✓	Yes				yes	1
	Reduce the input of raw materials			Describe the innovation in production process, in terms of lowering the input of raw materials?	No /Yes + explanatory anwswer	✓	Yes				yes	1
	Lower the natural ca	Contribution to th	Contribution to the biosphere	Are there elements, materials, etc. that contribute to the biosphere in the producing process ? (eg. Filtering the air quality, energy transported to the grid)	No /Yes + explanatory anwswer	✓	No	element			yes	1
	Streaming of the mat	Standardization	Prefabrication	Is the production an automised process? (people needed just for quality control)		✓	No	element			yes	1
	Lower the natural ca	Reduction of Gree	Greenhouse gas reduction in production	What is the amount of pre- consumer recycling in percentage?	No /Yes + explanatory anwswer(Describe in mass percentage how much Pre-consumer recycled material	✓	Yes	element				1
	Streaming of the mat	Materials for recyc	Materials for recycling	Which materials can be recycled (from the minable materials)							N.V.T.	1
	Streaming of the mat	Standardization	Prefabrication	What shape making processes are used (for this product)? (multiple techniques are possible, if N.A answer 'no' in the line)							yes	1
	Streaming of the mat	Standardization		Select: multiple possible: additive manufacturing	3D printing, deposition methods,photopolymerisation, sheet lamination, powder bed fusion	✓		Sheet lamination			yes	1
	Streaming of the mat	Standardization	Modularity	Select :multiple possible: casting	Die casting, investment casting, sand casting	✓		Investment casting			yes	3
	Streaming of the mat	Standardization		Select multiple possible: composite forming	Autoclave molding, pultrusion, resin transfer molding, vacuum molding, vacuum assisted rtm, BMC molding, filament winding, lay-up methods, SMC molding	✓		Autoclave molding		CNC	yes	3

	Streaming of the mat	Standardization	Modularity	Select :multiple possible: casting	Die casting, investment casting, sand casting	✓		Investment casting			yes	3
	Streaming of the mat	Standardization		Select multiple possible: composite forming	Autoclave molding, pultrusion, resin transfer molding, vacuum molding, vacuum assisted rtm, BMC molding, filament winding, lay-up methods, SMC molding	✓		Autoclave molding		CNC	yes	3
	Streaming of the mat	Standardization	Standardised Dimensions	Select: multiple possible: bulk deformation process	extrusion, forging, rolling, swaging	✓		Forging			yes	1
	Streaming of the mat	Standardization	Standardised Dimensions	Select: multiple possible: sheet deformation process	Sheet forming, Sheet stamping, drawing, blanking, spinning	✓		Sheet stamping			yes	1
	Streaming of the mat	Standardization	Standardised Dimensions	Select :multiple possible: machining (conventional)	Band sawing, Circular sawing, Cropping and guillotining, Drilling, Flame cutting, Grinding, Milling, Punching perforating blanking and nibbling,Shaping and planning, Turning boring parting	✓		element , Punching perforating		Bandsaw, drilling of holes	yes	3
	Streaming of the mat	Standardization	Standardisation	Select: multiple possible: machining (non-conventional)	Abrasive jet machining and cutting, electric discharge wire cutting, electro-discharge machining, laser cutting, water-jet cutting	✓		Electro-discharge machining			yes	3
	Streaming of the mat	Standardization	Standardised Dimensions	Select: multiple possible: moulding	Ceramic molding, Thermoplastic molding, Thermoset molding	✓		Ceramic molding, Thermoplastic molding, Thermoset molding			yes	1
	Streaming of the mat	Standardization		Select: multiple possible: powder methods	Powder injection molding, tape casting, pressing and sinterin, hot isostatic pressing	✓		Powder injection molding			yes	3
	Reduce the input of r	Durability -relation	Durability -relation to 'n'-life	What surface treatments are used? Multiple answers possible							yes	1
	Streaming of the mat	Monomaterial sep	Monomaterial separation	Select: multiple possible: heat treatments	carburizing and carbonitriding, induction and flame hardening, laser hardening, nitriding	✓		element			yes	1
	Streaming of the mat	Standardization		Select: multiple possible: painting and printing	cubic printing, electrophoretic and autophoretic painting, hot stamping, in-mold decoration, organic solvent-based painting, pad printing, silk screen printing, vitreous enameling, water-based painting	✓		element			yes	1
	Streaming of the mat	Standardization		Select: multiple possible: polishing/etching/working/texturing	Chemical posishing, Electro-polishing,Etching,Grinding and mechanical polishing,Texturing	✓		element			yes	1
	Reduce the input of r	Durability -relation	Durability -relation to 'n'-life	Select: multiple possible: Surface coatings	Anodizing,Electroless plating, Electroplating, Galvanizing, Metal flame spray, Polymer powder coating, Vapor metallizing	✓		Electroplating			yes	1
	Streaming of the mat	Standardization	Prefabrication	Which processes can run overnight?	No /Yes + explanatory anwswer	✓		element		?	yes	1
	Streaming of the mat	Stakeholder involv	Service contract	Are the machines used , hired by this company?	Yes /No + explanatory anwswer						yes	1
	Streaming of the mat	Standardization	Modularity	How much time does it take to produce 1 product	Open answer					?	yes	1
				How much time does it require from order to delivery of the product?	Open answer					?	yes	1
	Reduce the input of raw	Input of raw mate	Packaging	Describe the innovation in the packaging process concerning protecting the natural capital other than materials ?	No /Yes + explanatory answer	✓	Yes				yes	1
Transportation	Lower the natural ca	Waste disposed	Waste disposed	Describe the innovation in the packaging process concerning prevention of waste? -packaging (wrap/foils? / boxes, examples are described below:)	No /Yes + explanatory answer	✓	Yes			biobased(corc cardboard)+ polystyrene. LPDE film	yes	1
(LCA related)				E.g.All materials are Taken back through a system, buy-back, special arrangements, or any other way etc.) -The materials to wrap it in are from biological-renewable material and will be degraded as after unwrapping the				element			N.V.T.	1
	Lower the natural capital impact(other than materials)			Describe the innovation in packaging process in terms of lowering the input of raw materials?	Open answer Aspects such as the geology, soil, air and water. An example is the carbon footprint of saving in water usage.	✓	No	element			yes	1
				E.g. All materials for packaging can be re-used. - The packaging material are from post consumer material (recycled) – label cradle-2-cradle.				element			N.V.T.	1
	Reduce the input of raw	Input of raw mate	Packaging	Does the packaging have a sustainability label?	No /Yes + explanatory answer	✓	No	element			yes	1
	Lower the natural ca	Reduction of Gree	Greenhouse gas reduction in transportation	Describe the innovation in transportation process concerning protecting the natural capital?	No /Yes + explanatory anwswer	✓	Yes	element			yes	3
				Transportation concerns the choice of vehicles, distances, routes,combining transfer etc.				element			yes	1
	Lower the natural ca	Waste disposed	Waste disposed	Is there.Describe the innovation in transportation process concerning the prevention of waste?	Open answer. Packaging used for transportation, stacking of the elements	✓	No	element			yes	1
								element			yes	1
	Streaming of the mat	Stakeholder involv	Service contract and maintenance	Is there a deal/contract made of retrieving back the packaging material ?	No /Yes + explanatory answer	✓	No	element			yes	1
	Lower the natural ca	Stimuate the local	Local companies /technologies	Where are the products processed? answer the 3 following questions in the name of the city:				element			N.V.T.	1
	Lower the natural ca	Stimuate the local	Local companies /technologies	Location of the manufacturing/processing factory (could be this company)	Open answer			element		Europe	yes	1
	Lower the natural ca	Stimuate the local	Creating Local jobs	Location of the assembly place	Open answer	✓	element			Europe	yes	1
	Lower the natural ca	Stimuate the local	Local companies /technologies	Location of the sub suppliers :	Open answer			element		Europe	yes	1
Assembly	Streaming of the mat	Accessibility	Accessibility of the facade in general	Are the components easy to carry regarding the dimensions?	No /Yes + explanatory answer	✓	No	element			yes	3
	Streaming of the mat	Accessibility	Accessibility of the facade in general	Is the product vulnerable to weather conditions?	No /Yes + explanatory answer	✓	No	element			yes	1
	Streaming of the mat	Accessibility	Accessibility of the facade in general	e is the product prone to breaking? (do the builders on site need to be cautious?)	No /Yes + explanatory answer	✓	Yes	element			yes	3
	Streaming of the mat	Standardization	Prefabrication	What is the prefabrication level of the product?	not prefabricated/partly prefabricated+ explanatory answer/ totally prefabricated	✓	No	element			yes	1
	Streaming of the mat	Standardization	Standardisation	What is the precision and tolerances of the products?	Bouwbesluit/ better than bouwbesluit+ explanatory answer	✓	Yes	element			yes	3
	Streaming of the mat	Standardization	Standardisation	What parts are usually in superflu in this company ?	Open answer	✓	These	Material5				1
	Streaming of the mat	Standardization	Modularity	What will happen with excess elements (such as screws)?	Open answer	✓	N.A.	element			yes	3
Use & Maintenan	Streaming of the mat	Service&extension	Repair, remanuracturing & extension of life	Can (the components of the) product be replaced/repaired or remanufactured ?	No + explanatory answer /Yes + explanatory answer	✓	No	element			yes	1
	Streaming of the mat	Service&extension	Repair, remanuracturing & extension of life	Will this company be responsible of the repair/remanufacturing?	No /Yes + explanatory answerOEM/CR(Original manufacturer, contracted remanufacturer): IR:Independent remanufacturer:			element				1
				Can the components of the product easily be reached and replaced on site for maintenance or repair to extend the lif	Report on how well each component can be taken apart for maintenance and/or repair. A list of compone	✓	No				yes	1
	Streaming of the mat	Adaptability	Moveability	Which elements of the product can easily be reached and replaced on site for maintenance or repair to extend the lif	Report on how well each component can be taken apart for maintenance and/or repair. A list of compone			element			N.V.T.	1
	Streaming of the mat	Accessibility	Accessibility of the facade in general	In what period of time is cleaning arranged in the plan?	Open answer	✓	Yes	element			yes	3
	Streaming of the mat	Accessibility	Service contract and maintenance	Can this party be responsible for regular cleaning of the product?	Open answer	✓	No	element			yes	1
	Streaming of the mat	Stakeholder involv	Service contract and maintenance	In what period of time maintenance and repair is suggested/ needed?	Cleaning: Cleaning of the exterior side of the façade.Maintenance: surface threatening, painting, etc. Rep	✓	Yes	Material4		Washing needed, not in contract of AGC	yes	3
	Streaming of the mat	Accessibility	Service contract and maintenance	Is replacing of an element possible? what period of time is replacing the product suggested/ needed and arranged?	Describe the governing element	✓	No		element		yes	1
	Streaming of the mat	Accessibility	Service contract and maintenance	Is there good documentation of the product and the maintenance of it available for in the future? (e.g. Available in cloud, 3d models etc.)	Yes/No	✓	Yes				yes	3
	Streaming of the mat	Registration/quali	Registration/quality control	Is this company in charge of the (updating of) documentation of the product in the program used (BIM program, etc.) or tag system after (repair, refurbishment, replacement etc.)?	Choose	✓	This company is able to provide the project from an updated model of the product and/tag system (when				yes	1
	Streaming of the mat	Registration/quali	Registration/quality control	Does the product consist of multiple elements where cladding, insulation and structure are integrated in one closed component and thus where different levels of decay can be identified ?	Yes/ No + explanatory answer	✓	No				yes	1
	Reduce the input of r	Durability -relation	Durability -relation to 'n'-life	Who is supposed to disassemble the product? (for e.g. Repair/remanufacturing)?	Choose	✓	None of these above but an independent remanufacturing company could do it				yes	1
	Reduce the input of r	Service&extension	Repair, remanuracturing & extension of life	Who is able to disassemble the product? Repair/remanufacturing (Taken into account the tools and accessibility, this could also be the user himself)	Choose	✓	the use	element				1
	Streaming of the mat	Demountability	Demountability									2
	Streaming of the mat	Demountability		What Types of connections and fixations are in the product see the table? What Types of connections and fixations are in the product? See the table(multiple possible, start with the lowest number)		✓		Wood C24,	99.47%	I,V. But I is at the end of life separable	yes	1
	Streaming of the mat	Demountability		What Types of connections and fixations are in the product see the table? What Types of connections and fixations are in the product? See the table(multiple possible, start with the lowest number)		✓		Stro	32.43%	I,V. But I is at the end of life separable	yes	1
End-of-Life	Reduce the input of r	Stakeholder involv	Service contract	Is there a strategic revenue model to support retrieving the façade (parts) back after this set life span?		✓	No	Luchtdichte	32.43%			1
	Streaming of the mat	Stakeholder involv	Service contract	What part of the product will return to this company? (%)		✓	Yes	Wood C24	67.04%	I,II,V		2
	Streaming of the mat	Closing material circles	Closing material circles	Where would the product be totally dismantled? - location	(in the factory, closest selling point, different assembly hall, already in the hub)							
	Streaming of the mat	Materials for recyc	Materials for recycling	Which parts have the chance to be used again for new production (in this company) - e.g. New batch? - describe and give % (weight or volume)	could be for recyling in new batch. % of this element that will be used?	✓	N.A.	Stro	32.43%	I dont know yet		1
	Streaming of the mat	Closing material ci	Closing material circles	Which parts have the chance to be used again for new products in this company- by recycling or downgrading? - describe and give % (weight or volume)		✓	N.A.	Stro, plywoo	32.96%	I,II,V		1
	Streaming of the mat	Demountability	Demountability	Will the product be dismantled at the end of life? And how?	(machinery, people, combi)	✓	Yes			combi		
	Streaming of the mat	Stakeholder involv	Service contract and maintenance	How will the material be retrieved after end-of-life?	With the tag system and a set time before the end of life of the facade, the system, components, materials will be put on a harvesting database and thus be bought by interested parties.	✓	Yes					
	Lower the natural ca	Waste disposed	Waste disposed	What part(s) of the product will be discarded?	E.g. (e.g. Rubbers, screws, foils etc.), the outer layer of a product	✓	These	element , St	32.43%	III,IV	yes	1
	Streaming of the mat	Closing material ci	Closing material circles	Is there a tag system to enhance the diversifying reuse of materials for other applications in diverse branches?	No /Yes + explanatory answer	✓	No				yes	
	Streaming of the mat	Closing material ci	Closing material circles	Is the product allowed to be shown on harvest maps sometime before the whole facade will be taken apart?	No +explanatory answer /Yes + explanatory answer	✓	No	element			yes	
	Streaming of the mat	Closing material ci	Closing material circles	What will happen to the materials that will be but cannot be recovered inside this company?	keuze	✓	Yes	element , W	67.04%	Now, nothing	yes	2
	Streaming of the mat	Closing material ci	Closing material circles	If the previous question is answered with a yes : Which elements are not able to be recovered inside this company?	N.A. / Open answer	✓	No	element		But most materials should be able to cascade, however not	yes	1
	Streaming of the mat	Registration/quali	Registration/quality control	Is a software model provided with (the needed) information (e.g. BIM)?	No /Yes + explanatory answer	✓	No	element		All	yes	1
	Streaming of the mat	Closing material ci	Closing material circles	Are there elements or materials that will be sent back to the (sub) supplier?	Yes/No/Not needed as there is no subsupplier + explanatory anwswer	✓	No	Material5, L	67.04%	Zeolite		2
				E.g. Rubbers, screws, foils ,specific parts of the profiles							yes	1
Social-Economic	Streaming of the mat	Contribution to bi	Contribution to biodiversity	Can there be an option of environmental benefit for vegetation included in the product? (Which elements)	No /Yes + explanatory answer	✓	No	element			yes	1
	Streaming of the mat	Contribution to bi	Contribution to water	Will this product contribute to water collection (during use)?	No /Yes + explanatory answsrerith the element and volume storage /m2 facade	✓	No				yes	1
	Streaming of the mat	Adaptability	Adjustable	Are there limitations to the component/elements for the user?	No /Yes+ explanatory answer (if yees.Tick the elements)	✓	Yes	element		Wall at the interior should stay damp open	yes	3
	Streaming of the mat	Stakeholder involv	Knowledge transfer	How can the user be instructed on what not to do with the system? Describe options	e.g. With facade elements, paint it for a damp open system? Hufter proof, are they written on the eleme	✓	Yes	element		Protection with interior layers	yes	3
	Streaming of the mat	Stakeholder involv	Architectural influence	How involved is the architect in the design of this product?	No /Yes + explanatory answer	✓	architect is not involved			But any architect could get in touch with the company	yes	1
	Streaming of the mat	Energy generation	Insulation level	If this product is meant as an insulating part, which insulation level does it have?								1
	Lower the natural ca	Use of fresh water	Use of fresh water	how is in the process fresh water usage reduced?	Yes/No/Not needed as there is no subsupplier + explanatory anwswer	✓	No	Material5				1
	Streaming of the mat	Registration/quali	Registration/quality control	Is there a transparent chain network such as controlled with-cirlinq?	No					They work with Ecocon as supplier	yes	1
	Streaming of the mat	Registration/quali	Registration/quality control	Are the circular ambitions be set together with the whole network, and broadcasted to the outside world as a control	No /Yes + explanatory answer	✓	Yes			With the suppliers	yes	3
	Streaming of the mat	Stakeholder involv	Knowledge transfer	Will the performance of this product be monitored during use and reflected?	No /Yes + explanatory answer	✓	No				yes	1
	Streaming of the mat	Stakeholder involv	Knowledge transfer	Is the guarantee for reused products higher or more adequate than new products?	No /Yes + explanatory answer(if yes,click tick the elements)	✓	No	element		No experience yet	yes	1

§C.1.1 Facade contractor part- example

5.0 | System -											
Facade contractor panel 1 - Strotec											
			Question		Option			Answer		Standard of proof	Score
			How many different facade panels are there?								
			What is the quantity of products that are ordered for this project?		ea						
			What is the % of facade part that consist of this system?								
			Intended life duration [n=5]				✓	50 years			
			How many different products does this product exist of? (excluding connections/fixations such as glue)								
			Product 1		Glazing						
			Function of the product								
			Building surface m2								
			Volume % of the total element								
			Life span of this element [n=1]								
			Amount								
			Product 2		Window frame						
			Function of the product								
			Building surface m2								
			Volume % of the total element								
			Life span of this element [n=1]								
			Amount								
			Product 3		Window frame						
			Function of the product								
			Building surface m2								
			Volume % of the total element								
			Life span of this element [n=1]								
			Amount of products of product 3								
		total m2 of facade									
Materials											
Dismantling of the material output	Adaptability	Refitable	Is the insulation value adjustable in time?								
Lower the natural capital impact(s)	Energy generation/storage/expor	Insulation time!	Is the insulation value free to choose?								
Dismantling of the material output	Closing material circles	Closing material circles	Can the biobased materials be separated from the technical materials after service life?				✓	Yes			
			Technical materials. Finite materials. Technical materials are recovered and mostly reskined in the technical cycle. With biological materials is meant materials that encompasses the flows of renewable materials. These materials can be consumed. Renewable (biological) nutrients are mostly regenerated in the biological cycle. Describe in volume percentage how well the renewable (biological) and the technical materials can		Separation: 70-100 %ok Separation: 50-70 %medium, should be better Separation: 0-50 % "nowadays normal"					yes	
Reduce the input of raw materials	Input of raw materials	Input of raw materials	What is the amount of pre- consumer recycling?				✓	Yes			
			Describe in mass percentage how much Pre-consumer recycled material is used for each component? Pre-consumer is material that is rejected from the production line during manufacturing before the final product reaches the							yes	
		Secondary materials	What is the amount of post-consumer recycled material input?				✓	Yes			
			Describe in mass percentage how much Post-consumer recycled material is used for each component? Post-consumer is materials that do not longer function for its intended purpose generated by end users such as household or		80 -100% recottenil 60-80 % very good 40-60 %good 25-40 % ok , 5-25 % barely, 0-5% no recycled content					yes	
Reduce the input of raw materials	Input of raw materials	Input of raw materials	Are there toxic, hazardous chemicals in any form inside the materials of the product/ for the connections of the system?								
		Secondary materials	Is for the design of the facade already made use of reused materials/components?								
			Is for the design of the facade made use of reused energy in the near environment?								
Evolve the input of raw materials	Secondary materials	All use of Secondary materials requir	Is for the design of the facade made use of harvesting maps?				✓	Yes			
Design											
		Energy storage	Is there energy storage possible in the facade?				✓	Yes			
		Contribution to water	Is there contribution to water storage at the facade				✓	Yes			



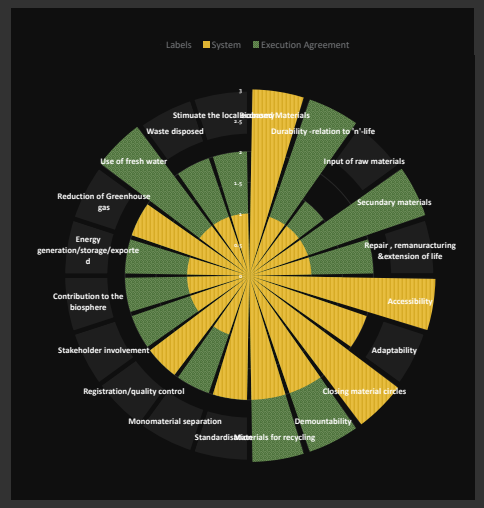


Figure c.2: Categories and subcategories as a result from the system.

D Timeline of all activities

May 13	Company visit Ferlem.
May 16	Company visit Hans Sluimer - Architect of BilT woning
May 26	Sannie Verweij- Gebouwinzicht & BREEAM assessor
June 03	Woud Jansen – Alba Concepts
August 13	Reigersbos location visit
September 12	Bouke Staphorst- Klimaatmissie Nederland
October 20	Thaleia Konstantinou - TU Delft
December 01	Rutger Snoek – Rijksoverheid
December 16	Baudoin Knaapen – Stichting Woon
January 26	Anton Peters-AGC Glass Europe
February 03	Gemeente Amsterdam Duurzame Gebiedsontwikkeling, presentatie
February 09	Dominique Vosmaer - Frontwise facades

• **Role**	• **Company/Institution**	• **Name of interviewee**
• Municipality	• Municipality of Amsterdam	• Maaike Zwart, Salomé Galjaard, Lianne Hulsebosch
• Project developer	• Stichting Woon	• Baudoin Knaapen
	• Rijksdienst voor Ondernemend Nederland	• Rutger Snoek
• Architect	• Klimaatmissie Nederland	• Bouke Staphorst
• Facade concultant	• Frontwise facades	• Dominique Vosmaer
• (Facade)contractor	• Ferlem	• Jan Deckers
• Supplier	• AGC	• Anton Peters

Table D1 :List of Interviewees for the tool.Own source

E

Biobased products

The misconception that forms bottlenecks on several biobased products. Many biobased materials have incorrect stigmas a few are summed up here:

Reed

Reed has a longer life span without big maintenance than most people expect. However, this material often has its origin in China, but there is potential to grow it in the Netherlands for production as well

Flax

This material is economical more beneficialthan current insulation products since there is no need to apply a damp tight sheet in renovation projects for the roof. There could potentially be enough flax to replace Rockwool, as it approaches the same lambda-value. Flax grows locally and is a residual product (of the fabric industry).

Straw

This material can be used as prefab insulated panels, extra insulation and internal walls. It has a high insulation value can be used as damp-open construction and can locally be produced. Misconceptions are about the fire safety, the life span, maintenance and insects while the products scores well on all these factors. Straw however, is not yet a commonly used building material (just 0.05% from the Dutch harvested straw is currently used for building projects) which result in high prices but this will change when the market will expand. Attention has to be given when installing straw panels, the product should be kept as dry as possible.

Bamboo

Bamboo can be used for floor finishing, paving, wall cladding, constructions but an unfair doubt on the quality of bamboo products are noted. The issue with bamboo is, however, the price and the product needs to be imported. Furthermore, there is a difference in the environmental the impact between treated and nontreated bamboo and bamboo. Nonetheless, the production of bamboo can grow with 25% in the coming five years and can be used in many different ways (NIBE, 2019).

Hemp

is used as lime hemp blocks, plaster, hemp sheet material and insulation. Als-The material quality is underrated. Hemp can grow without pesticides and is good resistant against mould. However, lime hemp is not 100% biobased and is relatively expensive. The production potential of this material is connected to legality. Cannabidiol-oil production can play a role in this.

Sheep wool

In the old environmental classification system sheep's wool was the best choice, however, this is no longer the case and even defined as 'unacceptable'. An important difference between the old and new database is that sheep wool was defined as waste material of sheep meat so no environmental impact was attributed. This is no longer the case and wool and meat share the environmental impact of keeping sheep and the emissions caused by this (NIBE, 2020).

F

Mat 8- BREEAM-NL

Rekentool Gebouwflexibiliteit

		0	1	2	3	WEGING	
Verkaveling (inrichting)							
1.	Kolomplaatsing	Casco				1	
2.	Verplaatsbare binnenwanden	Binnenafbouw				1	
3.	Voldoende aansluitpunten E-installaties	Installaties				1	
4.	Klimaat, E-installaties en W-installaties apart in te delen per stramien	Installaties				1	
							0%
Aanpasbaarheid (unitniveau)		0	1	2	3		
5.	Niet dragende functiescheidende wanden	Casco				2	
6.	Gebouwontsluiting	Casco				2	
7.	Niet dragende gevel en/of obstakels	Gevel				3	
8.	Unitgrootte, mogelijke indeling	Binnenafbouw				2	
9.	Zelfstandigheid unit, aanwezigheid pantry, meterkast & sanitair	Installaties				2	
							0%
Multi-functionaliteit (gebouwniveau)		0	1	2	3		
10.	Capaciteit draagvermogen	Casco				3	
11.	Toetreding van daglicht	Gevel				3	
12.	Hoogte Bovenkant vloer-Onderkant vloer (netto interne hoogte)	Binnenafbouw				2	
13.	Installaties binnen de (juridische) ruimte van de gebruiker	Installaties				3	
							0%

Casco	0%
Gevel	0%
Binnenafbouw	0%
Installaties	0%
Totaal	**0%**

Delen van deze tool zijn gebaseerd op de Real Estate Norm (REN) van Stichting REN en het onderzoek Open Bouwen (Flexis) van de TU Delft. Tot stand gekomen met medewerking van Ir. R.P. Geraedts.

1. Kolomplaatsing	Score
Kolommen binnen de gevel, stramien < 5400 mm	0
Kolommen binnen de gevel , stramien 5400 mm < 8100 mm	1
Kolommen binnen de gevel , stramien > 8100 mm	2
Geen kolommen binnen de gevel, vrije overspanning	3

2. Verplaatsbare binnenwanden	Score
Binnenwanden niet verplaatsbaar en niet afbreekbaar, meerdere functies	0
Binnenwanden niet verplaatsbaar; afbreekbaar maar niet herbruikbaar	1
Binnenwanden verplaatsbaar, demontabel en opnieuw op te bouwen	2
Binnenwanden eenvoudig verplaatsbaar, systeemwand	3

3. Voldoende aansluitpunten E-installaties	Score
Geen aansluitpunten	0
Aansluitpunt/goot in 1 richting in vloer, plafond of wand	1
Aansluitpunt/goot in 2 richtingen in vloer, plafond of wand	2
Holle vloer of computervloer	3

4. Apart in te delen installaties per stramien	Score
Geen indeling per stramien mogelijk	0
Alleen E-installaties mogelijk	1
E-installaties en W-installaties mogelijk, zonder ventilatie	2
E-installaties en W-installaties mogelijk, met ventilatie	3

5. Niet dragende functiescheidende wanden	Score
FS-wanden niet verplaatsbaar en niet afbreekbaar, meerdere functies	0
FS-wanden niet verplaatsbaar; afbreekbaar maar niet herbruikbaar	1
FS-wanden verplaatsbaar, demontabel en opnieuw op te bouwen	2
FS-wanden eenvoudig verplaatsbaar, systeemwand	3

6. Gebouwontsluiting	Score
Decentraal gecombineerde entree en kern	0
Centraal gecombineerde entree en kern	1
Gebouw verdeeld in 2 vleugels vv centrale gecombineerde entree en kern	2
Gebouw verdeeld in > 2 vleugels vv centrale gecombineerde entree en kern	3

7. Niet dragende gevel en/of obstakels	Score
Dragende gevel	0
Dragende gevel, 50% open oppervlakte of obstakels	1
Dragende gevel, 75% open oppervlakte of obstakels	2
Niet dragende gevel, geen dragende obstakels	3

8. Unitgrootte	Score
Groter dan 600 m2 BVO	0
Tussen 400 en 600 m2 BVO	1
Tussen 200 en 400 m2 BVO	2
Minder dan 200 m2 BVO	3

9. Zelfstandigheid unit	Score
Geen voorziening aanwezig	0
Één voorziening aanwezig	1
Twee voorzieningen aanwezig	2
Drie voorzieningen aanwezig	3

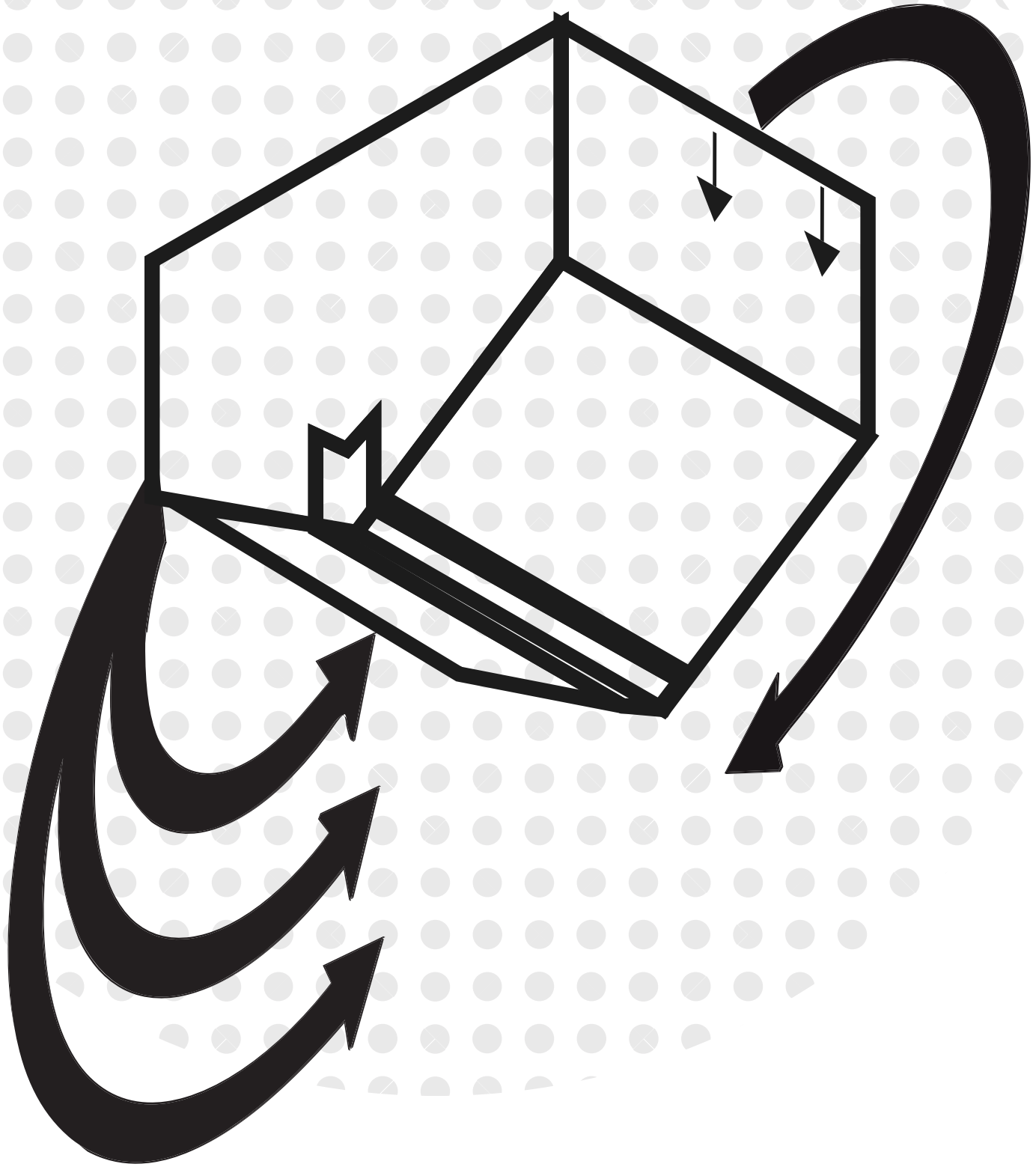
10. Capaciteit draagvermogen	Score
Veranderlijke 1,75 kN/m2	0
Veranderlijke 2,50 kN/m2	1
Veranderlijke 4,00 kN/m2	2
Veranderlijke 5,00 kN/m2	3

11. Toetreding daglicht	Score
Minder dan 70%	0
Tussen 70% en 85%	1
Tussen 85% en 95%	2
Tussen 95% en 100%	3

12. Hoogte bovenkant vloer-onderkant vloer	Score
Netto interne hoogte ≤ 2700 mm	0
Netto interne hoogte 2700-3000 mm	1
Netto interne hoogte 3000-3500 mm	2
Netto interne hoogte 3500- 4000 mm	3

13. Installaties binnen de (juridische) ruimte van de gebruiker	Score
Installaties/leidingen ingestort in de vloer	0
Installaties/leidingen over 2 bouwlagen verdeeld	1
Installaties/leidingen in één bouwlaag, boven of onder	2
Installaties/leidingen onder computervloer of in holle vloer	3

1 point: Score>33%
2 points: Score>50%
3 points: Score > 67%
4 points: Score >84%



The Circular Procurement Tool

The ambition of the Netherlands is to have a fully circular economy by 2050. One of the steps to achieve this ambition is that in 2030 the tenders should have circular ambitions at all governmental levels. However, at the moment, there are insufficient tools for the municipality to make the practical implications of these circular ambitions explicit. In a studied case-project in Reigersbos (Amsterdam), where circular facades are being applied, a selection procedure has taken place to unify different parties that are willing and able to enhance the circularity of the project. Such a tender process is complex and time-consuming. A tool that streamlines circular requirements can help the selection procedure for the parties involved early in the process and can actively keep track of realisation of the set requirements during the process. Therefore, the thesis aims to develop a circular tendering tool that actively helps the municipality and project developer set circular ambitions and criteria for an arbitrary project location. The tool's concept is to categorize and assess the individual benefits of the circular measures in the chosen products, phases and parties, based on the principle of the circular economy. By utilizing this tool, it becomes possible to compare and select a facade system for the project. Furthermore, it also keeps track of the process by monitoring the set goals during the project for necessary adjustments and allows evaluating of the goals in the end.

TU Delft

Gemeente Amsterdam