

R. M. H. Bos

Windows for Circularity

An analysis to identify circular interventions
in the different stages of the design process
of an office building

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By

R. M. H. Bos

Master Construction Management and Engineering

Delft University of Technology

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Author

Rosa Maria Hinderkien Bos
Student Nr. 4333500
+31 (0)645 727 901
r.m.h.bos@gmail.com

University

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Master Construction Management and Engineering

Thesis Committee

prof.dr.ir M.J.C.M. Hertogh (Chair, TU Delft)
dr. D.J.F. Schraven (First Supervisor, TU Delft)
ir. A.C. Bergsma (Second Supervisor, TU Delft)
W. Huurman (Company Supervisor, Arcadis)

Circulaire economie, soms werkt het dus wel om in kringetjes te denken

Loesje (2017)

Preface

2020 so far is the strangest and most disruptive year of my life. The pandemic virus COVID-19 controls people's lives. It influences the way we live, love and work. Offices are empty while people work from home. When, and if people are going to work in an office again like they were used to, is the question. The events of 2020 is an extra showcase that the way we use offices is subject to change. Digitalization and trends like open-plan offices, already changed the demand for office space. Office buildings have a lifespan of 30 to 300 years or even more. We should design them in a way that they are adaptable, reusable and can respond to changing needs. Circular design can help us to make our offices future-proof. Moreover, the use of sustainable or reused materials can have a positive effect on our health and on the planet. If you are interested and would like to know more about how to grasp opportunities for the circular economy in the design process of an office building, please continue reading.

The last half year I had the great opportunity to study the implementation of the circular economy in the design process of office buildings. Joining Arcadis and starting a challenging and interesting journey. I was supervised by a great committee, which supported me along the way and helped me to excel throughout the process. I would like to thank them. Marcel Hertogh for his sharp mind and kind words. Hans Bakker for taking the time and sharing his fresh perspective. Daan Schraven for helping me shaping my research, his fitting metaphors, and his extensive knowledge about methodologies. Arie Bergsma for his genuine interest and teaching practical insights about circular design. Wouter Huurman for his shared passion to make the world a little bit better and his smart advice. Moreover, I would like to thank my friends and family for their relentless support. With this thesis I wanted to challenge myself, immerse myself in the theory and practise of the circular built environment, and provide tangible results while enjoying the ride. Luckily I succeeded in reaching these goals, and I am more than happy with the results! Enjoy reading.

Rosa Bos
Rotterdam, September 2020

Executive summary

Research objective

The construction industry has an extremely large effect on its surroundings, the environment, and the amount of materials used (Levermore, 2008; ENEP, 2012; Lucon et al., 2014; WRI, 2016). Recently, the circular economy (CE) has taken the interest of scholars, practitioners, and politics as a promising approach to help reduce global sustainability pressures and avoid scarcity of materials without decreasing economic growth (European Commission, 2019; Ghisellini, et al., 2018; Bruel, et al., 2018; Adams, et al., 2017; Ghisellini, et al., 2018). CE presents a new economic system to replace the end-of-life phase with reducing, reusing, recycling and recovering of materials. It is more than just recycling of materials, it is a fundamental systematic change (Kircherr et al., 2017). The office building sector is interesting regarding circular design due to several reasons. First, the sector deals with a relatively high change rate of ownership or users. Second, the way we use offices is unpredictable and influenced by trends and unexpected events like the COVID-19 outbreak. Hence, office buildings could benefit extra when they would be designed according to circular design principles and are adaptable and reusable. Moreover, there is an increasing demand for sustainable offices. Therefore, this study focuses on circularity in the Dutch office building sector. According to Kingdon (1984), ideas can become solutions to a policy problem when a Window of Opportunity occurs. For a Window of Opportunity to form, three streams must be aligned: the problem, the politics, and the policy / solution stream. Due to the widespread interest in the circular economy and its potential benefits, there is now a Window of Opportunity for CE in the construction industry.

However, since the circular economy gained attention in the office building sector, only limited progress has been accomplished (Ghisellini et al., 2016; Stahel, 2016). When looking at a single building level, it is still a challenge to align the problem, policy, and politics streams. First, the involved actors must be aware that the current, linear material flows are harmful to the environment (problem). Second, possible design solutions must be known (policy/solutions). Third, the client must form an ambition which incorporates circularity of the office building and agree on design choices which aim to fulfil these (politics). Currently, this is complicated by the lack of knowledge about the possible circular design solutions. Moreover, in literature there is no circular design model specific for the building industry. Therefore, this research aims to develop a tool that stimulates the communication between client and designer and provides clarity about the possibilities of circular design. This information is much needed to accelerate the transition to a circular office building sector (Bekier & Vedel-Jørgensen, 2017; Kircherr et al., 2017; Platform CB'23, 2019; One Future Play, 2018). This leads to the following main research question: *'How can insight be created into possible circular interventions in the design process of an office building?'*

Method

The aim of the methodology is to describe how to design a decision support tool which helps to grasp opportunities for the circular economy in the design process of an office building. Thus, help create Windows of Opportunity. In order to do so, the Double Diamond method is chosen. The Double Diamond method is a design-based research approach. It is in line with the characteristics of the addressed research. The research has to cope with a lack of empirical evidence and addresses a complex problem in collaboration with practitioners (Fellows & Liu, 2015; Brown, 1992; Collins, 1992; Reeves, 2006; Herrington et al., 2007; Design Council, 2019). Because the Double Diamond method is an iterative research method. The development of the decision support tool was done in iteratively. This improves the internal and external validity of the research (Design Council, 2007; Design Council, 2019). To gather data for this research, 26 interviews with experts and 1 validating workshop were held, and 19 reference projects were studied, next to desk research.

Results

The results are displayed in the decision support tool (figure 1). It shows on which layer should be focused in what stage of the design process. On the Y-as the different layers of a building are shown with its different lifespans. On the X-as the stages of the design process are presented. The full-coloured boxes indicate that in these stages the circular decisions related to those building layers are made. In the initiation phase, no layers are presented because then all layers need to be discussed in regards to circularity. Circular interventions can be categorised into four themes. These four themes simplify the core principles of the circular economy and are easy to use in practise:

- A Adaptability.** Lifetime extension and avoiding waste streams through flexible design for multifunctional, continued use
- R Reusability.** Reuse (parts of) the building by Design for Disassembly, modularity, and detachable building components
- M Materials.** Reduce negative impact materials by reduction of amount of materials, use of recycled / bio-based materials
- P Process.** Enhance circularity through ambition and people management, business models and contracts

When starting a circular design process, the first step is to try to reduce the demand and with that the needed materials. Then choose the suitable circular focus. It is important to introduce circular interventions early. The impact of the interventions on the circularity of an office building decreases, as the design process progresses. Particularly, for long-lived layers early on decision-making is important. The structure has the largest environmental impact, as well as influences the design possibilities of all the other layers. At the end of the design process, decisions about the short-lived layers such as stuff can still be taken (figure 1). Practical examples of circular interventions which can be filled in the decision support tool are explained in chapter 5.

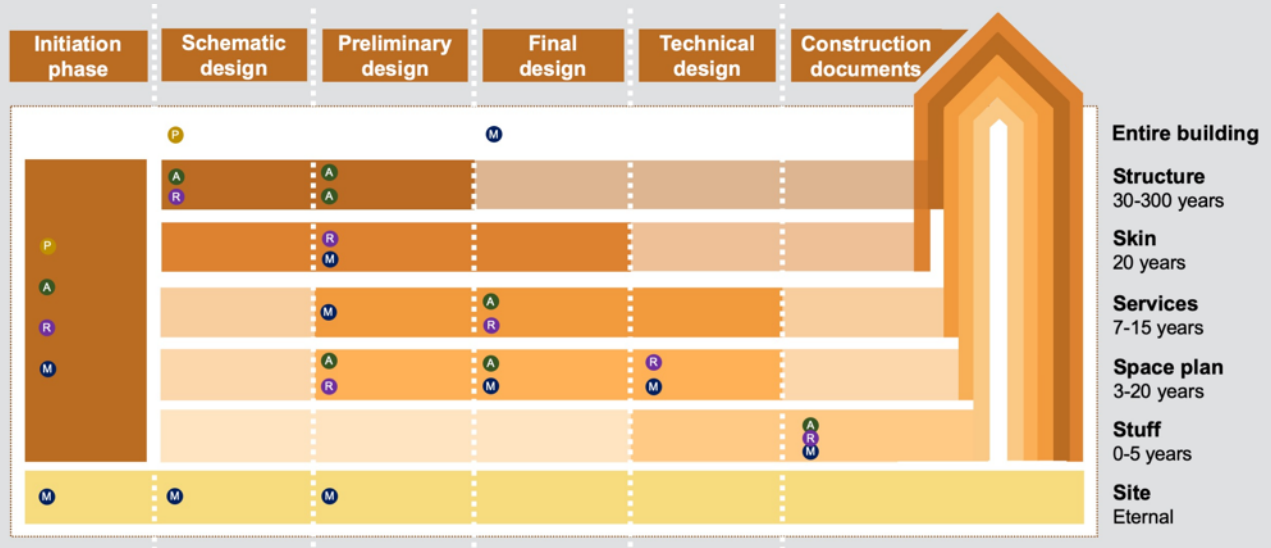


Figure 1– 'Windows for Circularity', the decision support tool

Discussion

The practical implication of this research is that it will help clients, designers, and other involved parties to give circularity priority in the design process of an office building project. The decision support tool provides insight into the possibilities of CE in the office building sector and helps identify specific design-choices based on their characteristics and the most suitable design stage. Nevertheless, achieving circular success in the development of an office building is still not easy. This is due to practical problems related to the fact that we are currently living in a linear world. Capitalism, legislation, and the perspective on circular design create barriers for the circular built environment.

Next to a practical implication, this research has also a scientific implication. Windows for Circularity can be seen as a study that specifies further on the conceptual models and incorporates ideas and research findings from state-of-the-art literature about the circular built environment. This study presents a model that is specific for the office building sector, which links circular strategies to actions (interventions) and places them on the timeline of the design process. This has not been developed before and adds to the body of knowledge.

Conclusion

In order to gain more insight into the possible circular intervention in the design process of an office building, three aspects of circular design need to be taken into account. First, a building consists of different layers with different lifespans that should be able to be refurbished, replaced, and recycled without damaging other layers. Resulting in an extended lifespan of the complete building and increased adaptability and reusability (Castro & Pasanen, 2019; Brand, 1994; Graham, 2005; Habraken, 1961). Second, practical circular interventions can be categorized into four themes which are based on circular theory. Those themes are adaptability, reusability, materials, and process. Third, decisions regarding circularity should be taken early in the design process. Especially when the lifespan of the building layer is long. These insights have been made transparent by means of a decision support tool.

As with any research, this study must also be considered in light of some limitations. These are mainly related to the small scale of this research and the occurrence of biases. For example, the research focuses on the technical aspects of circular design within the office building sector on building level. Due to this focus, some parts of the system are left out of consideration, resulting in a limited scope. To minimize the effect of the research limitations, extensive validation through literature, reference projects, and feedback sessions have been gathered and triangulation and strategic sampling is applied.

Recommendations

More research into implementing CE in the office building sector is advised. Testing the decision support tool on real-time cases would increase its usability and external validity. Another interesting follow-up research would be the generalisation of the research results to the complete building sector.

Moreover, practical recommendations can be given based on the research findings. First, get enthusiastic, immerse yourself in circular construction, study the decision support tool in this report, and get inspired by the different possibilities of circular design. Subsequently, involve parties who can help you to achieve your ambition to build a circular office and then just start doing. During the design process of a circular office, acknowledge that a building consists of different layers with different lifespans which should be able to be refurbished and replaced without damaging other layers. Moreover, the longer the lifespan of a building layer, the sooner circular interventions related to this building layer should be introduced in the design process. Lastly, keep in mind that circular construction is a method and not an aim. Therefore, developing a circular building should never be the highest aim, but a tool to build sustainable and future-proof instead.

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1 Introduction

1.1 Reading guide

This thesis consists of 7 chapters. Chapter 1 introduces the problem and the knowledge gap which this research tries to solve. In chapter 2 the research objective with its related research questions and scope will be defined. Chapter 3 focusses on the current, academic and non-academic, literature about the circular economy and circular design in the building industry and in specific the office building sector. Chapter 4 explains the used methodology. Chapter 5 focuses on the results. Chapter 6, the discussion, explains the implications of this research. The last chapter, the conclusion is given. In appendix A, a glossary is presented with all the used terms throughout this thesis. The other appendices will be referred to in the text. After each of the seven chapters a short summary is given. The executive summary of the complete research is presented in the beginning of this report.

The answer to the main research question is given in chapter 7, the conclusion. The first sub-question is answered in the summary of chapter 3, theoretical background. The second sub-question is answered in the summary of chapter 4, the methodology. The third sub-question is answered in the summary of chapter 5, results. The last sub-question about the implication of this research is explicitly answered in the summary of chapter 6, the discussion.

1.2 Background

The construction industry uses the most resources from all the industries. Implementing circular principles, within this industry would substantially improve the amount of used resources. Not producing large amounts of waste is just a decent manner of construction. However, it is surprisingly rarely applied in this sector.

There is increasing awareness of climate change which creates momentum for sustainable development. Sustainable development is a balance between its three dimensions, the economic, the social and the environmental dimensions. Governments and market parties increasingly aim for development which protects the planet from degradation through sustainable consumption, production and sustainably managing resources. Hereby, supporting the needs of the present and future generations (United Nations, 2015).

Contrary to popular thinking in various companies, the circular economy (CE) is not the latest sustainability trend or green program. It should not be thought of as just recycling, it requires a fundamental change in mindset. Our traditional mindset of the linear economy has prevailed for a very long period. The linear economy is a system which consist of a simple linear value chain of take-make-waste, or produce, construct, use, end-of-service (figure 2). Even though our linear system has become increasingly efficient, it still contains an incredible amount of waste. Essentially, at the end-of service stage the materials are dumped into landfills or incinerated. This

destroys nearly all value that was created earlier in the process. A circular economy on the other hand, tries to find ways to create loops in order to retain that value. Therefore, it is more than just recycling. Recycling is creating a loop which retains more value than disposal. However, a tighter loop such as refurbishment or secondary-life uses, retains more of the original value (McKinsey & Company, 2016; Thelen et al., 2018).

It is increasingly important to retain value of products and materials. This is partly because the current linear system puts a huge amount of pressure on resources and the ease of accessing these resources is going to reduce. This creates price volatility in most of the raw materials. Next to that, consumers are changing. New notions of ownership and new values in the context of collaborative consumption, can support the transition towards CE (Camacho-Otero et al., 2018). Moreover, regulations are changing as well. Governments are acting to reduce carbon emissions and use of energy and waste. These developments open a window of opportunity for the circular economy. However, there is still a long way to go in grasping the full potential of the circular economy (European Commission, 2019; Rijksoverheid, 2016; McKinsey & Company, 2016).

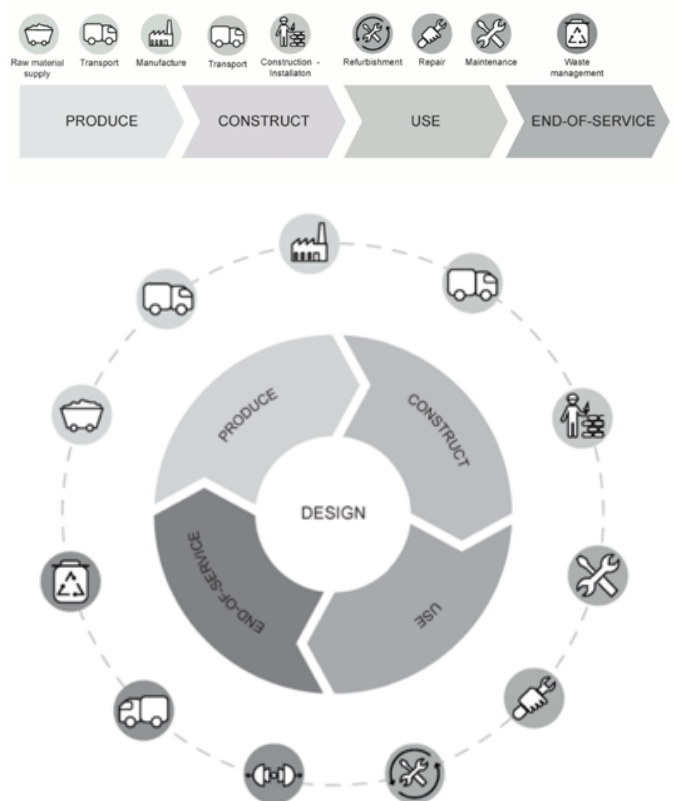


Figure 2 – The lifecycle of a building in a linear economy (top). This should be replaced by the closed lifecycle of a building in the circular economy (down). This closed loop aims at minimizing waste and emissions, as well as closing water, energy and material loops and avoiding disposal of economic and environmental value. (Klein, 2020)

1.3 Large potential for the Circular Economy in the construction sector

Urban areas account for more than 60% of the global energy consumption and generate approximately three quarters of global carbon emissions, of which buildings and infrastructure contribute to a significant extent (Seto, et al., 2014). Urban areas often exhibit inefficient use of resources and linear material flows (Huang & Hsu, 2003). Within this context, the construction sector has an large environmental impact, accounting for 40% of all material consumption, 33% of the CO₂ emission, and around 40% of all waste (Levermore, 2008; UNEP, 2012; Lucon, et al.; WRI, 2016). Because of the large environmental impact of the building industry, this industry plays a key role in the transition to a more sustainable world (Rijksoverheid, 2018).

The negative environmental impact of the construction industry should be reduced. This can, and should be done in different ways. A promising approach is implementing circular economy in the construction industry. Circular economy has attracted industrial and political interest as a suitable way to practice sustainability by potentially representing a way to overcome the contradiction between economic growth and environmental sustainability (Ghisellini, et al., 2018; Bruel, et al., 2018). CE moves away from the current linear system (take, make, use, waste). It replaces it with a circular system (reduce, reuse, recycle and recover). In theory, CE provides an economic incentive to work towards sustainability goals. If circular principles are implemented, resources can be managed as such that materials will be kept in use with an high value (Ellen MacArthur Foundation, 2019).

Moving to a circular economy system reduces the amount of primary materials used, protects material resources and reduce the carbon footprint. 'It is also predicted to bring economic benefits, including increases in gross domestic product, net material savings, employment growth and reduced risk of material price volatility and supply' (Adams, et al., 2017, p. 1; European Environment Agency, 2016; Ellen MacArthur Foundation, 2013; Morgan & Mitchell, 2015). However, the circular economy in the built industry has only recently gained academic attention. Across Europe, most research and activity has focused on end-of-life solutions to manage waste generation. This resulted in an overall improvement of waste management but much of this recovered waste is downcycled, where the value, quality and functionality are lower than the original product (Adams, et al., 2017; Eberhardt, et al., 2019). Therefore, widespread adoption of circular building practices, has still much potential to decrease the environmental impact of the sector without harming its economic value.

The Dutch government also sees the necessity of CE in the building industry and sets ambitious goals. According to the current ambitions, 50% less primary resources should be used by 2030. In 2050 the

government wants the economy be 100% circular. In order to achieve those ambitious goals, certain measures are (to be) taken. An uniform measuring method for circular buildings is being developed in order to be able to assess the circularity of a building. Moreover, the environmental performance requirements will be more strictly, including material performance. From 2023 onwards, public tenders will in principle be circular and subsidies for circular development are available (Ollongren, 2019; Rijksoverheid, 2018).

1.4 Research context

This research will be conducted in the context of the Dutch office sector. In paragraph 1.3 is explained why the construction sector has a large potential for CE. Within this sector, the building sector has the largest improvement potential. This is due to the relatively large amount of waste the building sector produces and its limited percentage that is recycled (3-4 %). In comparison, in infrastructure sector more than 50% of the used materials (excluding earthmoving) consists of recycled materials (Rijkswaterstaat, 2015). The office sector is a large and impactful part of the building sector with a large potential to improve its environmental impact. Therefore, this research focusses on the office building sector.

The company whom facilitates this thesis is Arcadis. Arcadis is a leading engineering & consultancy firm. The company has more than 28,000 employees, in over 70 countries. Around the world, its people are driven by their passion for improving quality of life. At Arcadis, sustainability means improving quality of life on our planet and of our people (Arcadis, 2020c). Circularity is gaining increased attention within the company. In the Netherlands, it is embedded in their sustainability ambition. Therefore, they try to incorporate it in their designs and consultancy work (Arcadis, 2020b).

The researcher of this thesis is a student at Delft University of Technology (also known as TU Delft). TU Delft is the oldest and largest technical university in the Netherlands. As of 2020, it is ranked by the QS World University Rankings among the top 15 engineering and technology universities worldwide. The university has 8 faculties with more than 19,000 students and employs more than 2,900 scientists and 2,100 support and management staff. Sustainability is like a threat in everything that the university does, education, research, valorisation, and business operations.

Knowledge will be obtained in this context of business and science. This positioning provides an excellent opportunity to explore the possibilities of CE within the Dutch office sector.

1.5 Problem statement

The circular economy has taken the interest of scholars, practitioners, and politics. The circular economy is viewed as a promising approach to help reduce global sustainability pressures and avoid scarcity of materials

(European Commission, 2019; Ghisellini, et al., 2018; Bruel, et al., 2018). Especially the building industry has great potential to reduce global sustainability pressures due to its great impact on the environment (Levermore, 2008; UNEP, 2012; Lucon, et al.; WRI, 2016). Moving to a circular system reduces the amount of primary materials used, protects material resources and reduce the carbon footprint. It is also predicted to bring economic benefits, including increases in gross domestic product, net material savings, employment growth and reduced risk of material price volatility and supply (Adams et al., 2017; Ghisellini, et al., 2018; Rijksoverheid, 2018). However, since the circular economy gained attention only limited progress has been accomplished in the building industry (Ghisellini et al., 2016; Stahel, 2016).

This is partly due to technical barriers, but mostly because of cultural, financial and market barriers. Cultural barriers such as the lack of consumer interest and awareness, are considered as important barriers to move to a circular economy. These are driven by market and financial barriers, such as lack of governmental interventions, high upfront investment costs, and limited funding of circular business models (Kircherr et al., 2018; Hart et al., 2019). The lack of knowledge on what CE in the building industry entails and how to achieve it, plays an important role in maintaining these cultural and market barriers (Hart et al., 2019). Circular buildings are perceived as difficult and more expensive. There is a lack of engagement, knowledge and skills throughout the supply chain. Therefore, practitioners are reluctant to develop circular buildings, or they do not give priority to circularity (Kircherr et al., 2017; Kircherr et al., 2018; Hart et al., 2019).

A problem within the office building sector is that insight in the possibilities of CE is lacking. There is no commonly agreed definition of circular economy in the building industry and measuring the impact is also perceived as a challenge. Therefore, it is susceptible to lack of understanding, misinterpretation and misuse among different stakeholders. Subsequently depriving CE from its underlying principles, impact and values (Bekier & Vedel-Jørgensen, 2017; Kircherr, et al., 2017; Platform CB'23, 2019; One Future Play, 2018).

Unclear circular expectations of the client, has been identified as a common problem faced by architects. Moreover, architects want to share knowledge about best practices of designing circular buildings (One Future Play, 2018). There are multiple interventions which stimulate CE in the building industry, those interventions have all different impacts on a building project in different phases of the life of a building. Therefore, which interventions are possible and best introduced in which stage of the design phase of an office, is often unknown or unclear. There are models that help identify the possible interventions. However, the most renowned models are not specified for the building industry and lack concrete, practical insights are missing (Ellen MacArthur

Foundation, 2017; Potting et al., 2017; Bocken et al., 2016).

It could be useful to have more insight in the different possible interventions, and to be able to distinguish in what stage of the design process of an office building a certain intervention could best be introduced. This could make designing a circular office easier because it supports the designers in their choices, and provides clarity about the possibilities of CE for client and designer alike. In conclusion, literature lacks insight into the possibilities of CE when designing an office building and when these circular interventions should best be introduced. This information is much needed to accelerate CE in the office building sector.

1.6 Knowledge gap.

Based on the literature review regarding CE in the office sector, the following knowledge gap has been identified:

In literature there is no circular design model specific for the building industry which links circular design strategies to actions (interventions). Moreover, knowledge about the placement of these circular interventions on the timeline of the design process is lacking.

This knowledge gap consists of two elements. First, the model itself. In literature there are several circular models for CE developed, however, those are not specific for the building industry. Due to the different characteristics of buildings than consumer goods, a different approach could be desirable. Especially, there is a lack of knowledge about concrete, building related, interventions which could be taken in line with the proposed circular strategies in those models.

Secondly, the placement of these circular interventions on the timeline of a design process. Not all circular interventions are as relevant as others in different phases in a building process. The design process is the most impactful phase in terms of the circularity potential of that building (Eberhardt et al., 2019). Within that phase, multiple stages can be identified; initiation phase, schematic design, preliminary design, technical design, final design, and construction documents (in Dutch: initiatieffase; schets ontwerp; SO, voorontwerp; VO, definitief ontwerp; DO, technisch ontwerp; TO uitvoerend ontwerp; UO). It could be useful to gain more insight in which stage of the design process some CE interventions have the most positive impact or is most easily implemented.

All in all, closing the research gap provides more insight for practitioners on how to achieve circular offices, and explain to their clients what the possibilities are for CE in the office building sector. Hence, this research helps the transition towards a circular built environment.

Summary chapter 1

**However beautiful the strategy,
you should occasionally look at the results**

Winston Churchill (1943)

The current linear economy of take-make-waste, can no longer be sustained. The construction industry uses the most resources from all the industries. Implementing circular principles, within this industry would substantially improve the amount of used resources. The circular economy (CE) is viewed as a promising approach to help reduce global sustainability pressures. It is also predicted to bring economic benefits, including increases in gross domestic product, net material savings, employment growth, and reduced risk of material price volatility and supply. Hence, CE has taken the interest of scholars, practitioners, and governments. (Adams et al., 2017; Ghisellini, et al., 2018; Rijksoverheid, 2018; European Commission, 2019; Bruel, et al., 2018; Ellen MacArthur Foundation, 2019). These developments open a Window of Opportunity for CE in the building industry.

Unfortunately, CE is still rarely applied in this sector. There is a long way to go in grasping the full potential of the circular economy (European Commission, 2019; Rijksoverheid, 2016; McKinsey & Company, 2016). This is partly due to the lack of knowledge on what CE in the building industry entails and how to design a circular building. As a result, practitioners are reluctant to develop circular buildings, or they do not give priority to circularity (Kircherr et al., 2017; Kircherr et al., 2018; Hart et al., 2019).

A problem within the office building sector is that insight into the possibilities of CE is lacking. Unclear circular expectations of the client, has been identified as a common problem (Bekier & Vedel-Jørgensen, 2017; Kircherr, et al., 2017; Platform CB'23, 2019; One Future Play, 2018). There are multiple interventions which stimulate CE in the building industry. Which interventions are possible and in what stage of the design process they are best introduced, is often unknown or unclear. There are models that help identify the possible interventions. However, the most renowned models are not specified for the building industry and lack concrete, practical insights (Ellen MacArthur Foundation, 2017; Potting et al., 2017; Bocken et al., 2016).

In conclusion, although there is a large potential for the circular economy in the office building industry, in literature there is no circular design model specific for the building industry which links circular design strategies to actions (interventions). Moreover, knowledge about the placement of these circular interventions on the timeline of the design process is lacking. This is the addressed research gap in this research and that information is much needed to accelerate CE in the office building sector.

2 Research objective

2.1 Introduction

This chapter presents the conceptual design of the research, this describes the what, why and to what level of detail the problem as stated in chapter 1 will be studied. It is the internal logic of a research project (Verschuren et al., 2010). The research objective, research questions and scope and practical and theoretical implications are given in the following paragraphs. A graphical representation on how those subjects relate to each other is shown figure 3.

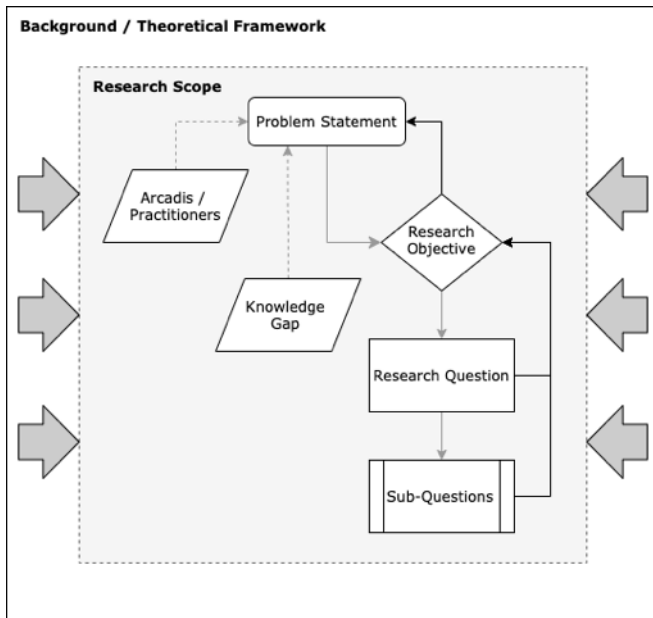


Figure 3 – Research process flow-chart. The grey arrows indicate decomposition of the problem statement. The black arrows show the successive steps in order to obtain the research objective. The existing knowledge gap, Arcadis, and practitioners provide input for the problem statement (own figure, based on Verschuren et al., 2010)

2.2 Research objective and questions

This research aims to help solve the problem introduced in chapter 1. The problem is that since CE has gained attention, only limited progress has been accomplished. Circular buildings are perceived as difficult and more expensive. There is a lack of engagement, knowledge and skills. It is many practitioners unclear what the possibilities of CE are for an office building, and when those should be introduced in the design process of a building. Therefore, the following research objective is formed:

‘Create insight into different circular interventions which can be taken in the design process of an office building. Hereby, developing a decision support tool to facilitate the communication between the client and designer about CE, and help designers to make deliberate and impactful circular design choices in the office building sector.’

This will address the research gap of the lack of a circular design model specific for the building industry which links

circular design strategies to concrete, and practical interventions, and show in which stage of a design process these interventions could best be introduced. This will be done alongside the main research question and the related sub-questions (SQ’s):

How can insight be created into possible circular interventions in the design process of an office building?

1. How can the circular economy be defined in the Dutch office building sector?
2. How to design a decision support tool which helps to grasp opportunities for the circular economy in the design process of an office building?
3. Within each stage of a design process, what could be circular interventions in the development of an office building?
4. In what way could the developed decision support tool be used and implemented in the office building sector?

In the first phase of the research, an explanatory research sub-question is answered (SQ1). This is necessary in order to explain how the circular economy is currently perceived in the Dutch office building sector. This lays the theoretical foundation of the research and sketches the playing field in which circular interventions can be implemented. It explains the building blocks and the framework of the decision support tool which is developed during this research.

The main purpose of this research is to help grasp opportunities for circularity in the office building sector. This is done by identifying the possible circular interventions and place them in the different stages of the design process. The second sub-question (SQ2) is a methodical question. Thus, developing a method on how to achieve that. In other words, how the data can be gathered and structured in such way that answers the main research question and helps to grasp opportunities for circularity.

The third sub-question (SQ3) focusses on the result of the upon decided methodology. This is important input to finally answer the main research question. The results will be shown in the form of a decision support tool. This enables the reader to walk through the possibilities of circular interventions in the different stages of the design process.

The last sub-question (SQ4) looks into the implementation of the research. The model has been validated and tested on its usability in the office building sector. Recommendations are given on how the model

could be implemented in the development of an office building.

The information gained by answering these sub-questions is needed to answer the main research question. It will deliver more insight in the possibilities of CE in the design process of an office building.

2.3 Research scope

In order to design a realistic research framework, scoping is essential. The area of research is circular interventions in the design process of an office building. Because of the limited size of the research, variables that can influence the area of research are not considered. An overview of the variables that are considered and those that are outside the scope, is shown in table 1. Figure 4 shows the theoretical framework of the research. The theoretical framework shows the topics which would be studied and with that, the focus of the research. The explanation why these scope choices are made, is described in this paragraph.

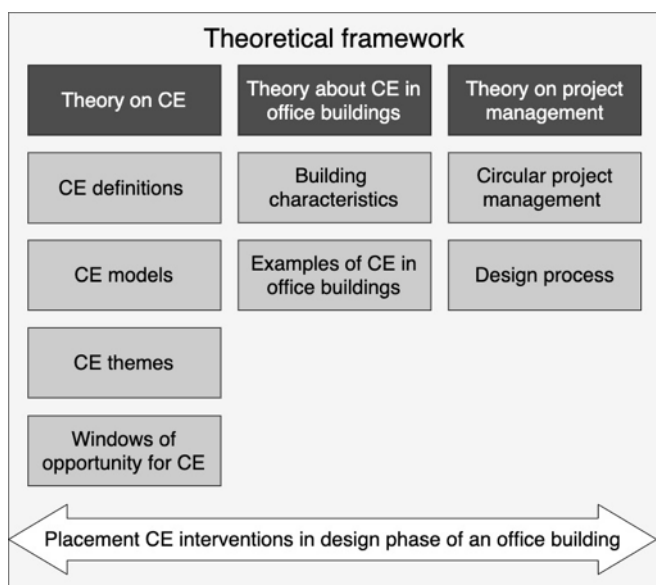


Figure 4 – Theoretical framework research

2.3.1 Why the office sector?

This research will be conducted in the context of the Dutch office sector. In paragraph 1.3 is explained why the construction sector has a large potential for CE. In short, this is due to the major environmental impact of this sector and the potential to significantly reduce this impact by implementing circular principles within this sector (Levermore, 2008; UNEP, 2012; Lucon, et al.; WRI, 2016; Adams et al., 2017; Ghisellini, et al., 2018; Rijksoverheid, 2018; European Commission, 2019; Bruel, et al., 2018; Ellen MacArthur Foundation, 2019).

Within the construction sector, the building industry has the largest improvement potential. This is due to the relatively large amount of waste the building industry produces and its limited percentage that is recycled compared to the infrastructure sector (Rijkswaterstaat, 2015).

Within the building industry, the focus of this research lies on the office building sector. A large and impactful part of the real estate portfolio is offices. The office building sector is an interesting sector when talking about circularity. This sector deals with a relatively high change rate of ownership or users. Next to that, the way we work and use offices is unpredictable and influenced by trends. Therefore, office buildings could benefit extra when they're designed flexible and adaptable. Next to that, the value of a building is strongly related to the rental price. Which depends on the demand. The trends is that companies are willing to pay more for a sustainable office. But is it enough to convince short-term investors? It is still a speculative sector with its fluctuating real estate prices. Long-term investors have more reason to invest in a circular building, namely because of the long-term added value of circular buildings (Specialist 5, 2020). Moreover, 26 institutional investors with \$ 4.7 trillion assets under management, declared that they want to have a carbon neutral real estate portfolio by 2050 (UNEPFI, 2019). Probably, more real estate investors will follow suit. Circularity could play a major role in achieving this which could lead to increased attention for circular offices (Specialist 5, 2020). Lastly, in research it is important to have a focus. In conclusion, due to all the aforementioned reasons this research focuses on the office building sector.

2.3.2 Why the design process?

The lifecycle of a building consists of several phases; design, built, use, end-of-life. The design process offers room for changing and adapting the building characteristics and process. This is the most impactful phase. In later phases, it will become harder to make impact. The cost for changes increases, while the impact of these changes reduces (figure 5; Wamelink, 2010; van Doorn, 2004). Therefore, the design process is when circular design methods should be introduced and chosen. It makes this phase the most impactful phase in the lifecycle of a building (Eberhardt et al., 2019; Merrild et al., 2016).

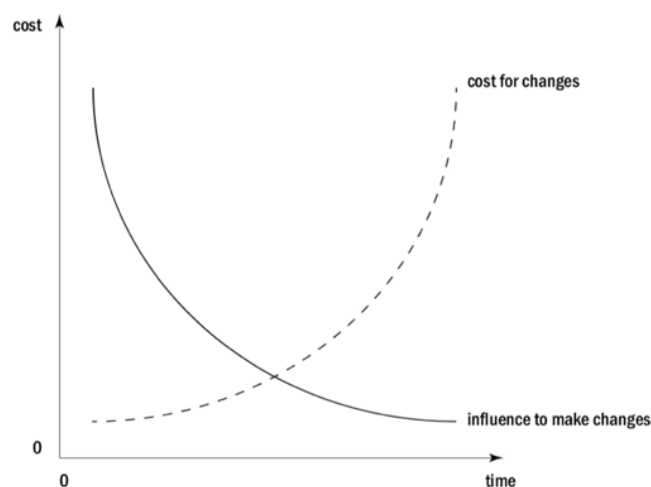


Figure 5 – Influence on and cost to change in the building process (van Doorn, 2004; Wamelink, 2010; Kibert, 2013)

2.3.4 Why this perspective?

The research will be conducted from the client, designer, and advisor perspective. The client is the one who wants to build a new office and pays for it. This can be a public or commercial party. The office can be built for own use, but also to rent out. Many different types of clients are possible. This does influence the project and the possibilities for a more circular office. However, the influence of the type of client is not the focus of this research.

The designer are all parties involved with the design of the office. This is the architect, but also constructors and installation technicians. The advisor can be a sustainable advisor. But it can also be the project manager from an engineering and consultancy firm which advises the client.

The aim of the research is to facilitate the communication between the client and designer about CE, and help designers to make deliberate and impactful circular design choices in the office building sector. The

focus of this research is on those parties, because those parties benefit the most from more insight in the possibilities of different circular interventions which can be taken in the design process of an office building.

2.3.5 Why focus on technical aspects?

Soft and regulatory aspects are important in order to realise a circular building. Cultural, market, and financial barriers are believed to be the main source of the lack of implementation of CE in the office sector. However, these are partly created by a lack of understanding the technical possibilities and their impact (Kircherr et al., 2018; Hart et al., 2019). Therefore, this research focusses on the technical aspects in order to improve those misunderstandings and improve the communication. This has added value in multiple contract and collaboration forms for all type of clients.

Area of research	Outside the scope
Office sector	All other building sectors
All stages of the design process (initiation phase, schematic design, preliminary design, final design, technical design, construction documents)	All other life cycle phases; construction, use, end-of-life
Building scale	All other scales; global, regional and city scale
Perspective: client, designer, advisor	All other perspectives such as supplier, contractor, user, etc.
Focus on technical aspects	Soft and regulatory aspects are only mentioned; contract and collaboration form, methods to promote CE such as 'as-a-service' contracts, no influence of type of client; public/private, investor/owner

Table 1 – Research scope

Summary chapter 2

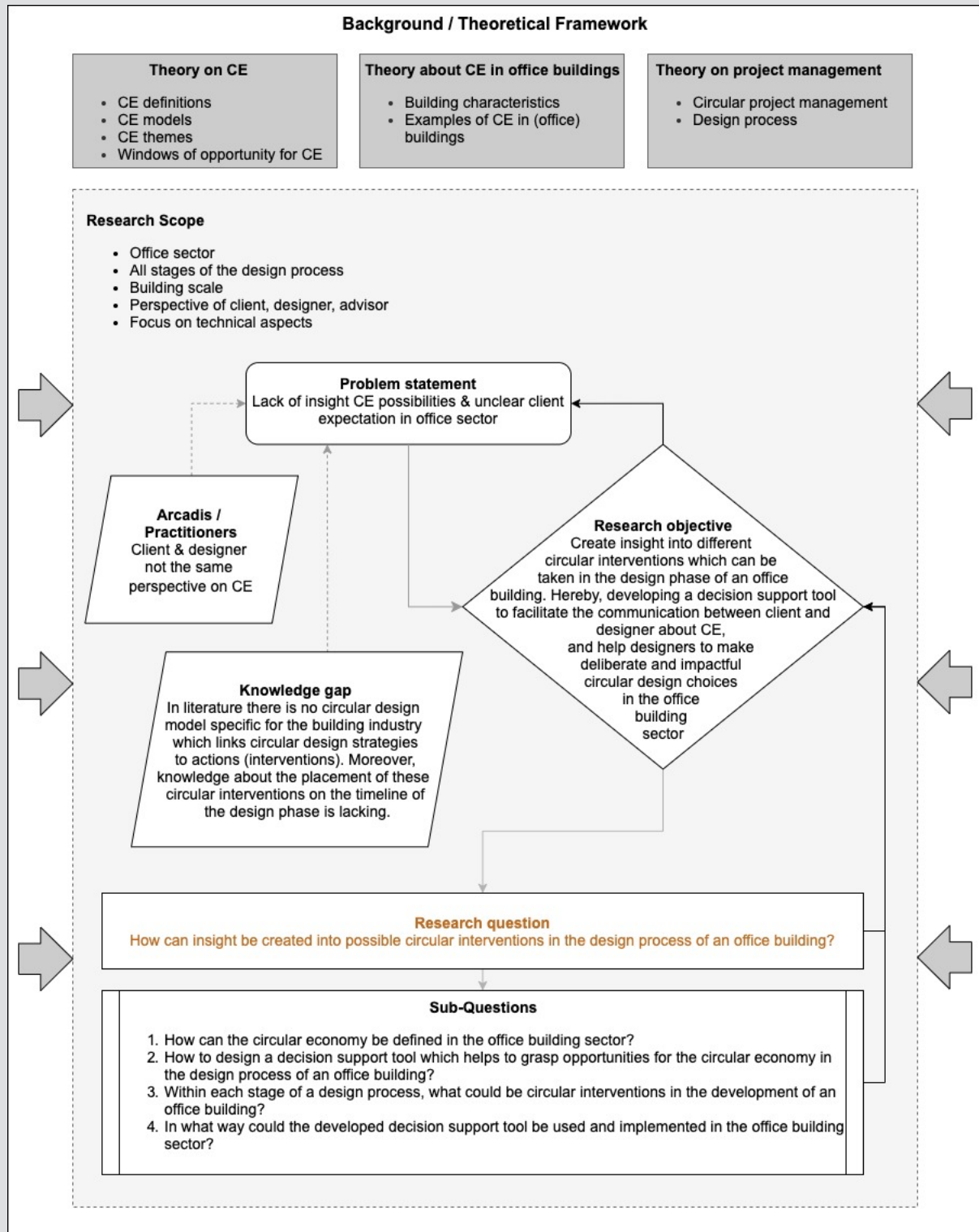


Figure 6– Relations between research objective, problem statement, theoretical framework, scope, and research questions

Figure 6 summarises what has been discussed in chapter 2. It provides an overview of the research objective, problem statement, theoretical framework, scope and research questions. This is the filled in process flow-chart shown in the beginning of chapter 2 (figure 3). The grey arrows indicate decomposition of the problem statement. The black arrows show the successive steps in order to obtain the research objective. The existing knowledge gap, Arcadis, and practitioners provide input for the problem statement.

3 Theoretical background

3.1 Introduction

This chapter presents the theoretical background from which the research will depart. Starting with defining the CE in the building industry and the conceptual models to explain CE and how they could apply to buildings. Themes related to circular interventions will be explained. The different building layers and their importance for circular design are explained as well. The design process underlying the development of a building is outlined. An introduction into circular project management will be given. An overview of the Dutch construction sector in relation to CE will be sketched and the characteristics of the Dutch office sector will also be explained. Lastly, the theory of Windows of Opportunity is explained. This was the inspiration of the title of this thesis.

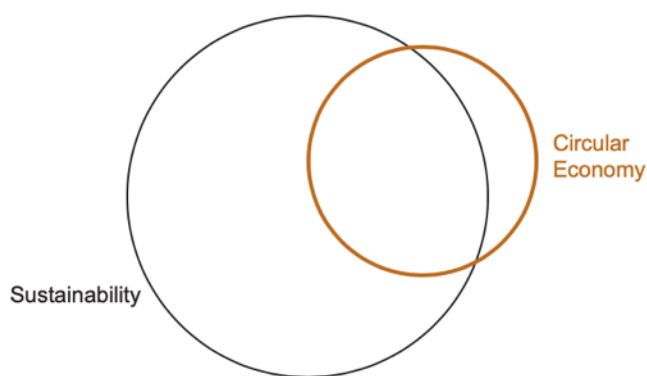


Figure 7 - CE in relation to sustainability (own figure)

3.2 Defining the Circular Economy

The circular economy (CE) concept is trending among practitioners and scholars alike. This combined with relatively recent interest and limited research, the concept of the circular economy may be unclear for stakeholders. According to Kircherr et al. (2017), who analysed 114 definitions of CE, CE means many different things to different people. In essence, CE is an economic system that replace the end-of-life phase with reducing, reusing, recycling or recovering of materials. It is more than just recycling of materials, it is a fundamental systematic change (Kircherr et al., 2017). This report uses the definition of the Ellen MacArthur Foundation, which is one of the most widely supported definitions by both scholars and practitioners. Based on this definition, the Dutch definition of circular construction and a circular structure is developed. This is done in cooperation with market- and governmental parties (Ellen MacArthur Foundation, 2017; Platform CB'23, 2019). In Figure 8 the important definitions in this report are defined, more used definitions are explained in the glossary (appendix A).

Sustainable development

Is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987, p. 49)

A circular economy

is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation, 2017, p. 1)

Circular construction

is the development, use and reuse of buildings, areas and infrastructure, without unnecessarily depleting natural resources, polluting the living environment and affecting ecosystems by using as many renewable raw materials as possible. Building in a way that is economically, socially, culturally and ecologically responsible. Here and there, now and later (Platform CB'23, 2019, p. 3)

A circular structure

is a structure that: as been designed and implemented in accordance with circular design principles and has been realized with circular products, elements and materials (Platform CB'23, 2019, p. 3)

A circular intervention

Is an action which is in line with a circular theme. A circular intervention aims to design out waste and/or pollution and/or keeping products and materials in use and/or regenerating natural systems

Figure 8 - Important definitions (list of all definitions can be found in appendix A)

3.3 Circular models

In the last decades, various circular models have been developed in order to support and explain circularity. Those models account for optimal use of materials, energy and water resources to reduce environmental impact. Well-known models are the resource and value strategy based on Stahel, Butterfly Model, and the widely used R-models. Those models and the more holistic Doughnut Model of Raworth (2017) are described in the following paragraphs.

3.3.1 Doughnut Economics of Raworth (2017)

A new way of economic thinking is introduced by Kate Raworth, a English economist working for the University of Oxford. The Doughnut Economy, as she calls it, could be the answer to the challenges the 21st century faces. It takes the social and planet boundaries into account in the means of a social foundation and an ecological ceiling. The ecological ceiling is derived from the planetary boundaries from Rockstrom et al. (2009). Beyond them lies unacceptable environmental damage and potential tipping point for the system of the planet. The internationally agreed minimum social standards derived from the sustainable development goals (United Nations, 2015) are the basis of the social foundation. Between the social and planetary boundaries lies the sweet spot in which humanity and nature can thrive (figure 9; Raworth, 2017).

The doughnut model of Raworth (2017) gives many impact areas for a sustainable world. That this model looks at the whole system is good and provides insight and also represents the line of thought of the circular economy. However, because of these many impact areas the Doughnut Economy enhances, it is complex to define

strategies and monitor their impact. A more practical approach to support the circular economy, are models which are developed in order to achieve circularity. Those models account for optimal use of materials, energy and water resources to reduce environmental impact. While implementing those strategies, it is important not to neglect the social foundation and take biodiversity, human culture, health and wellbeing into account.

3.3.2 Resource and value strategy based on Stahel (1982, 1994, 2010)

Resource strategy

Stahel (1982, 1994, 2010) was an early adapter of circular thinking. With that he developed a resource strategy based on circular principles. He distinguishes fundamentally different systems, the closed, circular systems and the open, linear systems. Within a closed loop system, there are two different loops 'reuse of goods' and 'recycling of materials'. Reuse of goods means an extension of the utilisation period, which result in a slowdown of the flow of materials. Recycling of materials is the closing of the material loop between post-use waste and production and does not influence the speed of the flow of materials through the economy. Bocken et al. (2016) developed a model based on the work of Stahel (1982, 1994, 2010) and McDonough & Braungart (2013) with a third dimension; narrowing flows (figure 10). Narrowing flows aims at resource efficiency, fewer resources per product. Narrowing flows approach is different than the slowing resource flow and the closing resource flow approach, because it does not aim to keep the materials in the system but aims to reduce the amount going into the system. The

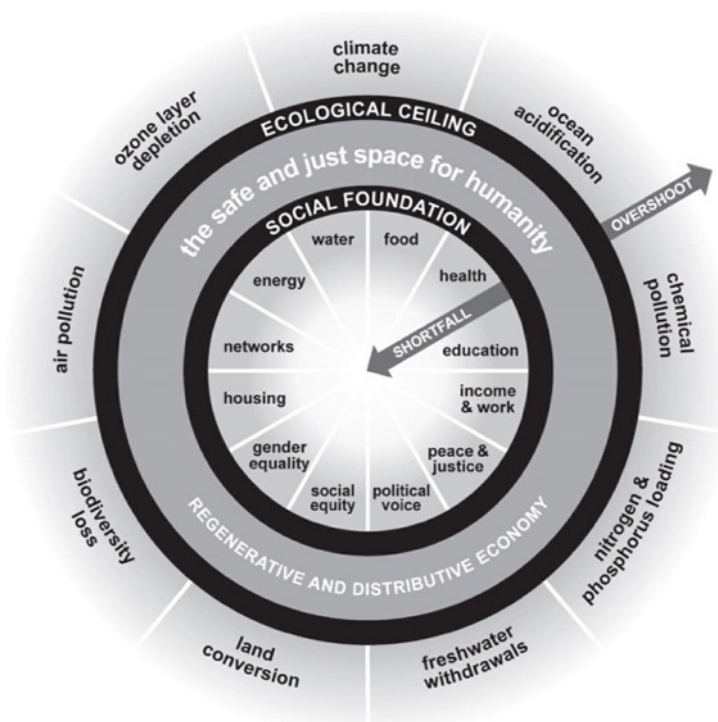


Figure 9 – The Doughnut Economy (Raworth, 2017)

narrowing flows approach is already successfully applied within a linear system.

The model of Bocken et al. (2016) introduces a list of design strategies and business model strategies to facilitate the transition to CE, categorized on the types of loops presented in the model. These strategies apply to all products, and does not specifically pays attention to buildings. Therefore, this model depicts mainly a conceptual way of thought and distinguishes different linear and circular flows. The work of Bocken et al., 2016) makes it more concrete by adding design and business model strategies. However, these strategies are not specifically designed for the building industry which has substantially different characteristics than the consumer goods market.

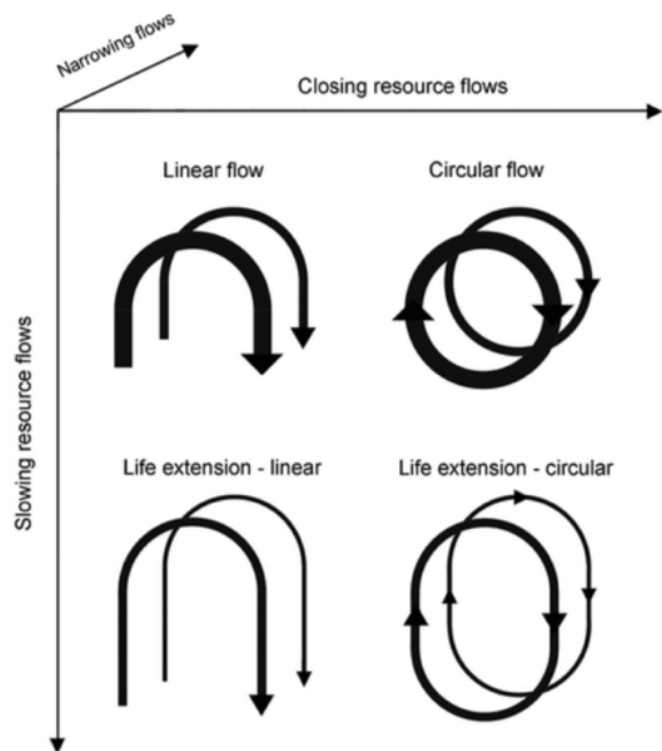


Figure 10 – Resource strategy of linear and circular approaches for reducing resource use (Bocken et al., 2016)

Value strategy

In addition to the resource strategy, value strategies can be identified. The value strategies relate to the resource strategies. Circularity aims to create and retain value. Or even, decrease value but not waste value of materials (Lüdeke-Freund et al., 2018; Kircher et al., 2017; Carra & Magdani, 2017). Narrowing resource flows relate to reducing material input & output. Slowing resource flows relates to retaining component value. The value of the complete building or large parts of it. Closing resource flows relates to retaining material value and find useful application of materials (Lüdeke-Freund et al., 2018).

3.3.3 Butterfly model of the Ellen MacArthur Foundation

The Butterfly Model is a famous conceptual system diagram of the circular economy (figure 12; Ellen MacArthur Foundation, 2017). It tries to explain that in a circular economy, material cycles are closed. In a fully circular economy, there is no such thing as waste, because every residual flow can be used to make a new product and with that close the loop. In this system, it is not only important to close the loop, but also that the products, components and raw materials remain of high quality (Korhonen et al., 2018).

It shows a distinction between the biological (left) and the technical (right) cycle. It highlights the continuous flow of biological and technical materials through the 'value circle'. In the model there is a distinction made between users and consumers. In a circular economy, biological materials are can be thought of as consumable, while technical materials are used. This raises the question about the necessity of owning products as we do in a linear economy. It is about the function a product fulfils, not the product itself (Ellen MacArthur Foundation, 2017).

The model succeeds in explaining the concept of the circular economy in one figure. The model also provides ideas on how to achieve circularity. On the other hand, the model is high level and is developed for all goods and not in particular for the building industry. Therefore, the model can only be used for input for design strategies for buildings.

Prevention & reduction

Preventing and reducing waste and material use is perceived as the preferred aim of material use (Lansink, 1979). Preventing and reducing waste can be done by evaluating the need for a building and the size of a building. Also lightweight materials and resource efficient construction and manufacturing processes play a role (Lüdeke-Freund et al., 2018). Prevention and reduction is displayed in the Butterfly Model as renewables flow management, stock management, minimise systematic leakage and negative externalities, and share (Korhonen et al., 2018; Ellen MacArthur Foundation, 2017).

Maintain & prolong

The aim of maintain and prolong is to extend the lifespan of the complete building or building components. Future-proof and adaptable designs increase the change of prolonged lifespans. Design for easy maintenance and a proper executed maintenance plan also increase the potential lifespan of a building and its components (Lüdeke-Freund et al., 2018; Ellen MacArthur Foundation, 2017; Korhonen et al., 2018). Maintain & prolong refers to the second, right, inner cycle of the Butterfly Model (Ellen MacArthur Foundation, 2017).

Reuse & redistribute

Redistribution is sometimes necessary in order to reuse building components or even complete buildings because on-site reuse is often not possible. Currently, facilities for sorting and reusing old materials are still in development. Moreover, the specifications of those materials are often unknown. Improving the facilities to reuse and redistribute materials and building components, could stimulate the use of secondary materials (Gorgolewski, 2008). Reuse & redistribute refers to the second, right, outer cycle of the Butterfly Model (Ellen MacArthur Foundation, 2017).

Recycle, refurbish, remanufacture

The outer right cycle of the Butterfly Model is related to recycling, refurbishing and remanufacturing. Whereas recycling is related to downcycling. Refurbish and remanufacture is about upgrading the performance of an already existing component, without changing its function. The difference between reuse and redistribute is the need for large alterations to the building or building components (Ellen MacArthur Foundation, 2017).

Biological cycle

Left cycle of the Butterfly Model is the biological cycle. Bio-based materials can be in a closed loop by means of biomass conversion and composting (Ellen MacArthur Foundation, 2017; McDonough & Braungart, 2009). According to McDonough & Braungart (2009) this process requires separation of biological and technical materials.

3.3.4 10R model

R models built onwards to the way of thinking of the Ellen MacArthur Foundation (Butterfly Model) and Stahel (1982, 1994, 2010) and incorporates design approaches similar to the circular approaches of Bocken et al. (2016). Moreover, it prioritises the circular design approaches. Narrowing flows is related to R0-R2, slowing resource flows is related to R3-R7 and closing resource flows is related to R8 and R9. Next to that, it shows similarities with the technical cycle of the Butterfly Model (figure 10; figure 11; figure 12; table 2).

In figure 11, the 10R model is displayed. Other R models have similar sets of strategies (i.e. Reike et al., 2018; Allwood et al., 2011; Bakker et al., 2014). Those R models are used as well, they vary in amount of categories and the hierarchy between them. But the principles of each R model are equal (Kircherr, et al., 2017; Potting, et al., 2017). The aim of an R model is to explain the 'how-to' of CE. The model uses the line of thought of the more conceptual circular models from the Ellen MacArthur Foundation and Stahel, and transforms them into strategies. The added value of this model is that it prioritise the strategies and that it is easy understandable for practitioners. The downside is that the model is also not

primarily focused on the building industry, it takes products in a broader sense (Potting et al., 2017).

Potting et al. (2017) categorised the 10 R's in three sections. Smarter product use and manufacture, extend lifespan of product and its parts, and useful application of material.

Smarter product use and manufacture

The most impactful is the first, smarter product use and manufacture (R0-R2). Refuse, rethink and reduce are strategies which are closely connected to design. It's about a new way of thinking and design in which the demand can be decreased (Morseletto, 2020; Potting et al., 2017).

Extend lifespan of product and its parts

The second section (R3-R7) refers to strategies that focuses to retain products longer in use, while maintaining or improving their value. The corresponding strategies are reuse, repair, refurbish, remanufacture, and repurpose (Morseletto, 2020; Potting et al., 2017).

Useful application of materials

The third (R8-R9) relates to recycling (downcycling) and recovery (incineration) of materials. The yield rates are often low, and the process often expensive and therefore, R8-R9 strategies have relatively little influence on the system. Nevertheless, most circular policies are currently focused on these strategies (Ghisellini et al., 2016; Potting et al., 2017).

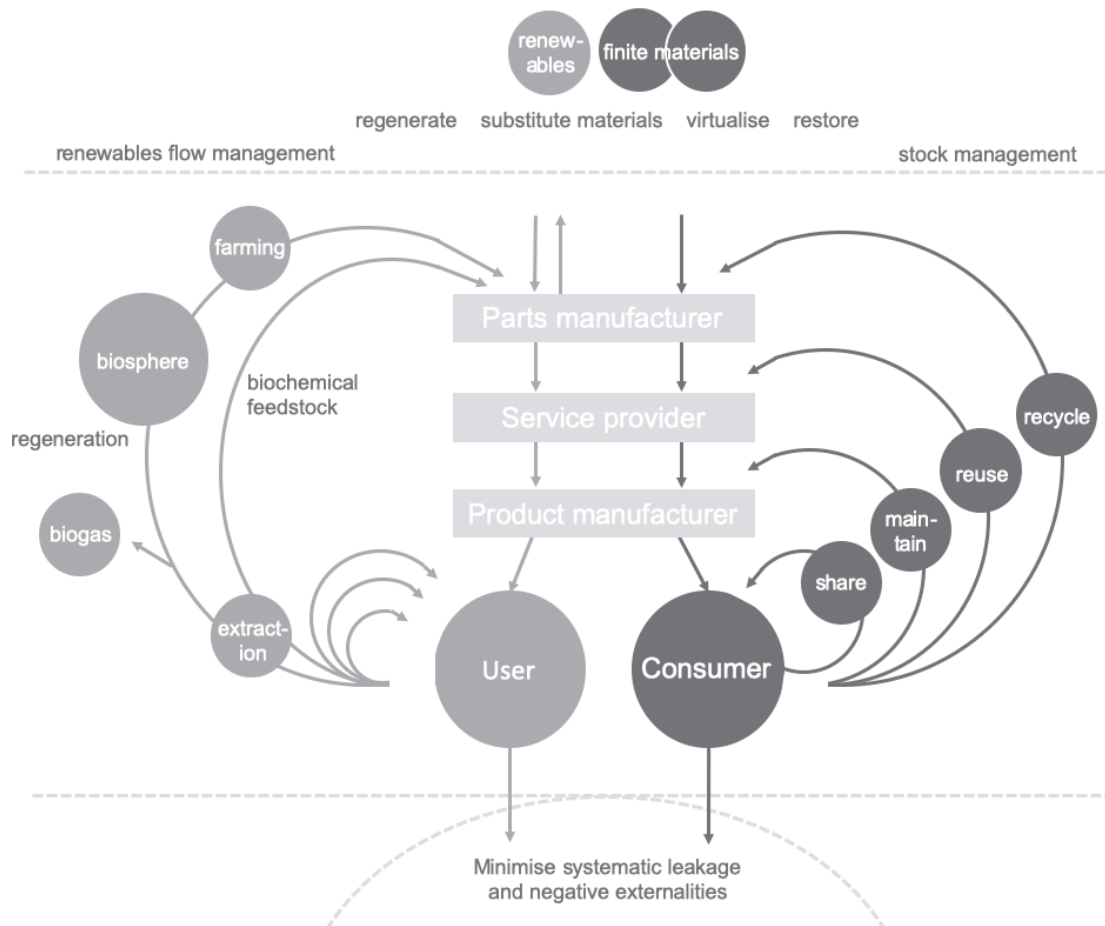


Figure 12 – The Butterfly Model (own image, based on Ellen MacArthur Foundation, 2017)

Circular economy		Strategies	
Increasing circularity Linear	Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
		R1 Rethink	Make product use more intensive (e.g. by sharing product)
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
	Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
		R9 Recover	Incineraton of materials with energy recovery

Figure 11– The 10R Framework (own figure, based on Potting et al., 2017)

3.4 Circular themes

Different circular themes can be identified. When talking about circular construction, four topics regularly arise in literature and in practise. These topics are adaptability, reusability, materials, and process. All interventions can be grouped into one of these themes. Figure 13 briefly describes these themes. The following paragraphs dive deeper into the circular themes and their meaning.

Table 2 shows the literature corresponding with three out of four circular themes named into this report. This forms the academic foundation of the circular themes. The fourth theme, process does not relate to circular design itself but to the process on how to get there. The academic foundation of this theme is explained in this paragraph and in paragraph 3.7 about circular project management. In the design of some reference projects, certain themes had more attention. The themes that are visible in certain reference project are shown in appendix F. This provides examples of the application of the themes in practice.

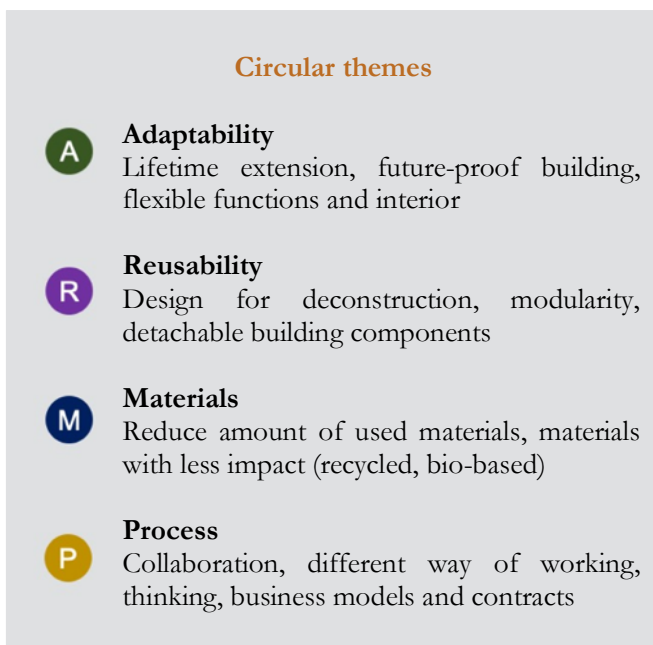


Figure 13 – Circular themes

3.4.1 Adaptability

Adaptability refers to a building design that can easily adapt to change. The aim is lifespan extension and avoiding waste streams. It's about buildings with a flexible design for multifunctional and continued use. A building that is future-proof.

Adaptability is related to the second loop of the technical cycle of the Butterfly Model, maintain & prolong (Ellen MacArthur Foundation, 2017). The resource strategy is slowing down and the value strategy is, maintain component value (Stahel, 1982; 1994; 2010; Bocken et al., 2016; Lüdeke-Freund et al., 2018). Extend lifespan of product and its parts is the correlating section of the 10R framework (Potting et al., 2017).

Habraken (1961) introduced the term of open buildings. These are buildings which makes a division between two domains: the robust structural support or base building, and the changeable infill or fit-out (figure 14). This 'open building' approach is often seen as the basis for Design for Adaptability (DfA) in which flexibility is paramount.

Adaptability can be divided into a set of subthemes. Those are; plan for change, design for long-life, and design for loose-fit (Graham, 2005). Adaptability has two principal theoretical propositions; a building is not a static object, and a building consists of several layers with different lifespans (Graham, 2005; Duffy, 1990; Brand, 1994). Because buildings are not static but a dynamic system of different layers, in a adaptable design there should be planned for change (Graham, 2005; Habraken, 1961; Duffy, 1990).

Design for long-life refers to a durable structure. Designing a structure that is strong enough to cater different uses. The dimension of structural frames should also be designed to assist adaptation. Also a structural grid that permits modularity of skin and space plan could improve the adaptability. How services can be improved over time should also be included. Another important aspect of maintaining a building's function and value is creating an indoor environment that is good for people. We tend to preserve buildings in which we feel good (psychologically, health- and comfort-wise). Design for loose-fit refers to designing for spatial flexibility and structural flexibility.

Design for loose-fit requires flexible connections between the building layers so that layers with a short lifespan can be replaced without damaging the layers with a long lifespan. This has some overlap with the theme reusability. This approach increases next to the adaptability of the building, the ease of deconstruction. Design for Disassembly complements Design for Adaptability. Therefore, the theme adaptability goes hand in hand with the theme reusability (Graham, 2005; Guy & Ciarimboli, 2008; Macozoma, 2002).

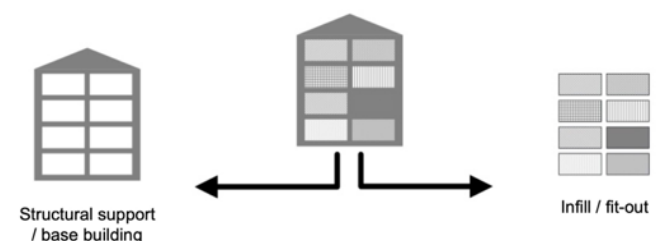


Figure 14 – The concept of adaptable, open buildings (Cao et al., 2018)

3.4.2 Reusability

Reusability refers to the possibility to reuse (parts of) the building. It relates to the well-known term of Design for Disassembly (DfD). This facilitate future change and the eventual dismantlement (in part or whole) building. Important aspects of this themes are design for deconstruction (DfD deconstruction), design for

detachable building components (DfD connections), design for modularity (DfD standardisation).

Reusability is related to the right cycles reuse & redistribute, recycle, refurbish, and remanufacture of the butterfly model (Ellen MacArthur Foundation, 2017). It aims at extending the lifespan of a product and its parts and the useful application of materials (Potting et al., 2017). It slows down, as well as closing resource flows. The value strategy is retaining component and material value (Stahel, 1982; 1994; 2010; Bocken et al., 2016; Lüdeke-Freund et al., 2018; table 2).

The use of dry joints is a must when it is desired to disassemble a building. The connections should be accessible and easy to disassemble. The use of bolted, screwed and nailed connections, within a standard and limited set of connectors, increases the simplicity in which a building (or parts of it) can be disassembled (Graham, 2005; Guy & Ciarimboli, 2008).

Design for deconstruction addresses a bigger task than the use of easy detachable connections. Such a building is designed to be completely deconstructed after its functional lifetime. The parts are designed in a way that they are easy to disassemble and a reusability plan has been drawn up (Graham, 2005; Guy & Ciarimboli, 2008). Examples of such projects are the temporary courthouse in Amsterdam, Amsterdam International Community School, and the city hall in Venlo.

Standardisation is also another aspect in the reusability of a building. The use of interchangeable components and units will facilitate reuse. This is the concept of modular building (Guy & Ciarimboli, 2008)

This theme focuses on the reusability of a building. It is a technical solution, aiming at reducing the negative environmental impacts of buildings. However, whether the components and materials are actually reused or recycled in the intended way is outside the scope. Therefore, the promised positive impact of these circular interventions is not guaranteed (Geldermans, 2016).

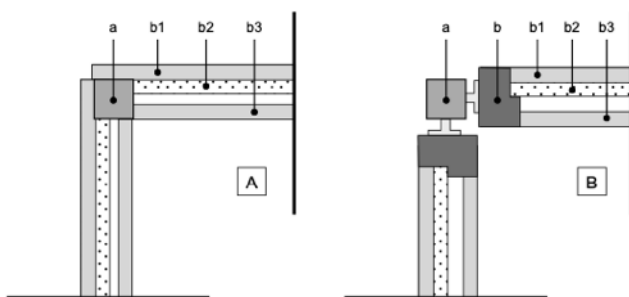


Figure 15 – Wall section A is not designed for disassembly, wall section B is (Durmisevic & Brouwer, 2002)

3.4.3 Materials

The theme materials refers to the type of materials and the amount of it used. The aim is to reduce the materials used and use materials with less impact. This is done by efficient design and construction, use of recycled materials and bio-based building.

The theme materials relate to the complete left cycle of the Butterfly Model and the right outer cycle, recycle (Ellen MacArthur Foundation, 2017). The resource strategy is narrowing as well as closing resource flows. This relates to a value strategy reduce component and material in- and output and retain material value (Stahel, 1982; 1994; 2010; Bocken et al., 2016; Lüdeke-Freund et al., 2018). Smarter product use and manufacture and useful application of materials are the correlating section of the 10R framework (Potting et al., 2017; table 2).

The aim of the circular economy is to reduce the consumption of raw materials (Kircherr et al., 2017). The most obvious theme is therefore about materials. Circular interventions related to this theme directly influence the amount of materials used of what kind of materials used. The use of non-toxic, quality materials that could be and/or already is been reused, recycled or is bio-based (Thelen et al., 2018; Architect 1, 2020). Reduction of materials can be achieved by efficient construction, lean design, and the use of light materials. The choice of the construction material influences the environmental impact and the characteristics of the building (Addis, 2006; Klein, 2020).

3.4.4 Process

The development of a circular office is supported by a certain process. When designing a circular office some elements of a process should receive more attention. For example, setting of ambitions and broad collaboration with early involvement. A sound process helps to achieve the circular interventions and grasp opportunities for circular development.

Implementing circular economy principles into your project calls for a new way of thinking. Next to technical solutions such as adaptable and reusable with conscience use of materials, other ways of use can also decrease your demand of materials. Think about new business models where you share services. Stakeholders that can bring added value to the project. Also think about which kind of contract suits your collaboration goals, is that a more integrated contract or a co-creation or a regular D&C contract? What are the digital solutions that will Revise the financing options. If the aimed office building believed to decrease absenteeism, a larger budget may come available. In the same way, great positive side effects for people and planet could generate value (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019; Specialist 6, 2020; Specialist 8, 2020).

In paragraph 3.6 and 3.7 dive deeper into this subject. Paragraph 3.6 explains the design process and the executive steps that are taken in this phase. Paragraph 3.7 provides guidelines on how circular project management should be done.

	Smarter product use and manufacture	Extend lifespan of product and its parts		Useful application of materials		R-model
	Prevention & reduction	Maintain & prolong	Reuse & redistribute	Recycle, refurbish, remanufacture	Biological cycle	Ellen MacArthur
Adaptability						
Plan for change	✓	✓				
Design for long-life	✓	✓				
Design for loose-fit		✓	✓			
Reusability						
DfD deconstruction			✓	✓		
DfD connections			✓	✓		
DfD standardization		✓	✓	✓		
Materials						
Reduce materials	✓					
Reused materials	✓		✓	✓		
Bio-based materials	✓				✓	
	Narrowing resource flows	Slowing down resource flows		Closing resource flows		Resource strategy
	Reduce component & material input & output	Retain component value		Retain material value		Value strategy

Table 2 – Coupling circular themes adaptability, reusability and materials with principles in circular models. Based on Potting et al. (2017), Ellen MacArthur Foundation (2017), Stahel (1982; 1994; 2010), Bocken et al. (2016), and Lüdeke-Freund et al., (2018), Habraken (1961), Guy & Ciarimboli (2008), Graham (2005), Duffy (1990), Durmisevic & Brouwer (2002), Thelen et al. (2018)

3.5 Building layers for circular design

A building can be decomposed into different layers. As shown in figure 16, there are six building layers, with all different lifespans. This concept is known as shearing layers and was first developed by the architect Frank Duffy and later elaborated by Brand (1994). The understanding of shearing layers enables to increase the circularity potential of a building from the start.

The implications of the first two layers, site and structure, are the most impactful. This is because their lifespan is long. Placing a building has a lasting impact on its site. For designing a circular building, it is also important to consider what is already there. The structure is the foundation and load bearing structure. This is the longest lasting of the built elements. When designing the structure, it is important to know for how long the building should last. If there in essence should be a building for eternity at a certain location, the structure should be very robust and flexible. If the lifespan of the building is already defined and is short, then it is important to build the building in a way it can be easily disassembled (Brand, 1994; Geldermans, 2016)

The skin of a building lasts for 20 or more years. This are the exterior surfaces such as the roof, siding, sheathing and windows. Not all elements of the skin wear out at the same rate. If the elements with a short lifespan can easily be replaced and reused, this could sustainable increase the lifespan. The skin has a large impact on the long-term durability, the user comfort, energy performance and its attractiveness of a building (Brand, 1994).

The services in a building have a lifetime of 7-15 years. The plumbing, heating, cooling, ventilation and electrical systems are part of the services. According to Brand (1994), the longevity of buildings is often determined by how well they can absorb new services technology. This knowledge should be considered when designing a building.

The space plan of a building has an average lifespan of 3-30 years. The space plan are all parts of the buildings which are mutable and changeable without changing structure, services, or skin. This are among others, walls, surface finishes, and doors. The problem with the space plan from a circular perspective, is that it is often changed because of new fashion trends or taste from the new user.

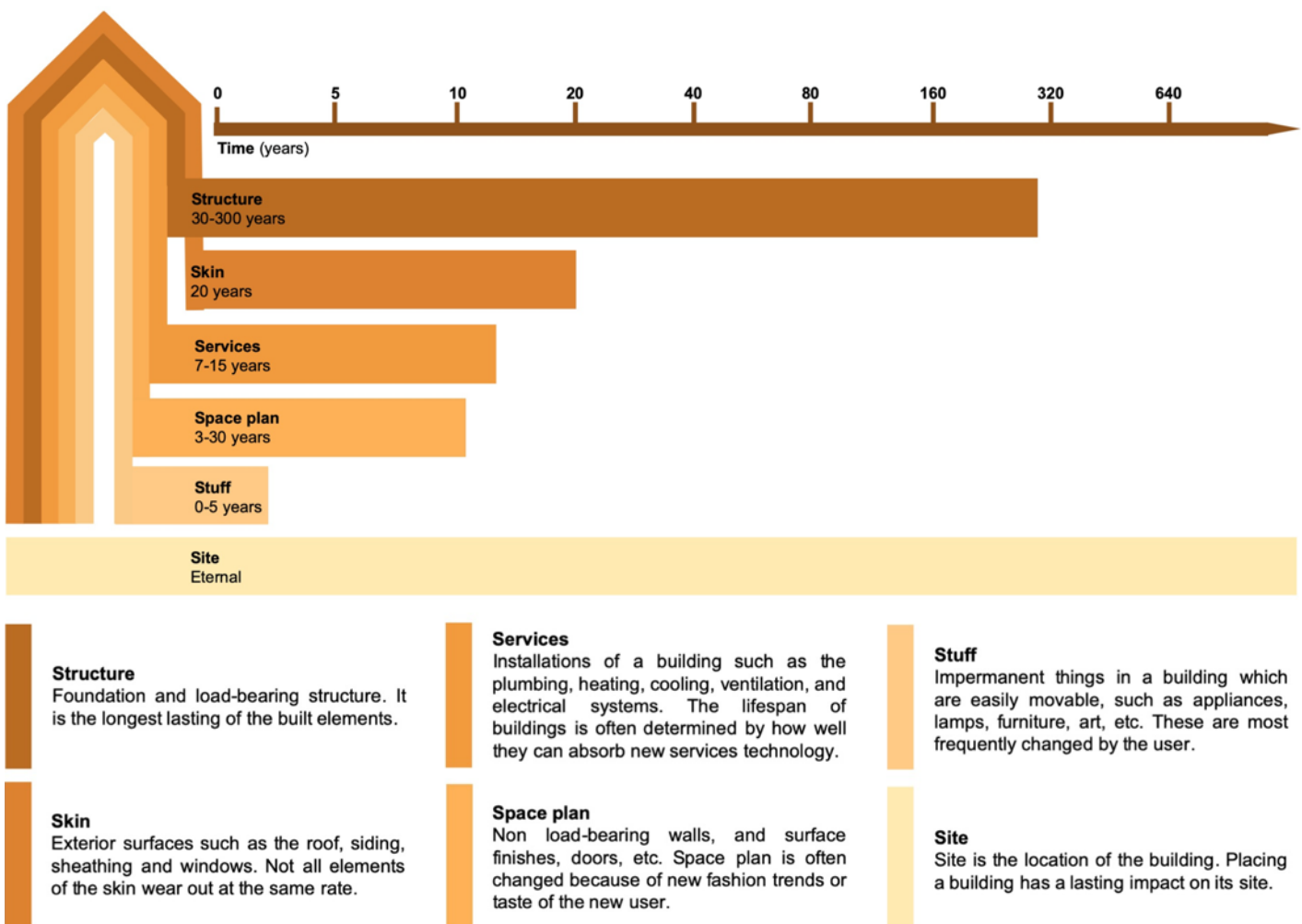


Figure 16 – Building layers and their expected lifespan (Brand, 1994; Crowther; 2001)

The stuff within a building has a short lifespan, according to Brand (1994) 1 day to 1 month. According to Crowther (2001), the average life of stuff is more, and is around 1-5 years. Stuff are the impermanent things in a building which are easily movable, such as appliances, lamps, furniture, art, etc. These are most frequently changed by the user (Brand, 1994).

The structure, skin and services depend on each other. The heating of a room depends on its services, which depends on the energy efficiency of the skin, which depends on the constraints of the structure. Therefore, those three layers should not be designed separately from each other (Brand, 1994).

The notion of the different layers of a building is important for the design of a circular building. Each layer offers different opportunity to increase the lifespan of the entire building. If a layer can be replaced or refurbished without touching other layers, this could substantially increase the flexibility and thus the lifespan of that building. The inner layers (stuff, space plan, services) are subject to the limitations of the outer layers (site, structure, skin). Each layer has its own dynamics and sensitivity. Therefore, taking the building layers into account when designing a circular building, is of utmost importance (Thelen et al., 2018; Brand, 1994; Crowther, 2001).

3.6 Design process of an office building

The design process is the most impactful phase in regards to the possibilities of CE in the office sector (Eberhardt et al., 2019). Because of the high impact of the design process, this research focus on the design process. Figure

17 shows a schematic representation of the design process. It consists of the initiation phase and the design phase.

The design process can be divided between stages; initiation phase, schematic design, preliminary design, final design, technical design and construction documents (in Dutch: initiatieffase, SO, VO, DO, TO, UO).

In the initiation phase the feasibility and the demand are analysed. Based on this, the requirements of the building will be established. Traditionally, then contracting parties will be found to design and build the building. The program of requirements differs from level of detail depending on the project and chosen contract form (Arcadis, 2020a; BNA & NL ingenieurs, 2014).

In the schematic design (Dutch: schetsontwerp; SO) is the first stage, the requirements of the client, the possibilities and limitations of the site, and the environmental factors, are combined and translated in the first drawings. Multiple options are still under discussion in this phase (Arcadis, 2020a; BNA & NL ingenieurs, 2014).

The design decisions made in SO lead to the preliminary design (Dutch: voorontwerp; VO). VO is the first spatial and aesthetic elaboration of the project. This will be presented to the client with 3D visualizations and possibly a marquette of the building. The client can react on this preliminary design with feedback. Based on that the design can be adjusted (Arcadis, 2020a; BNA & NL ingenieurs, 2014).

After all the required adjustments are made to the preliminary design, the final design will be developed

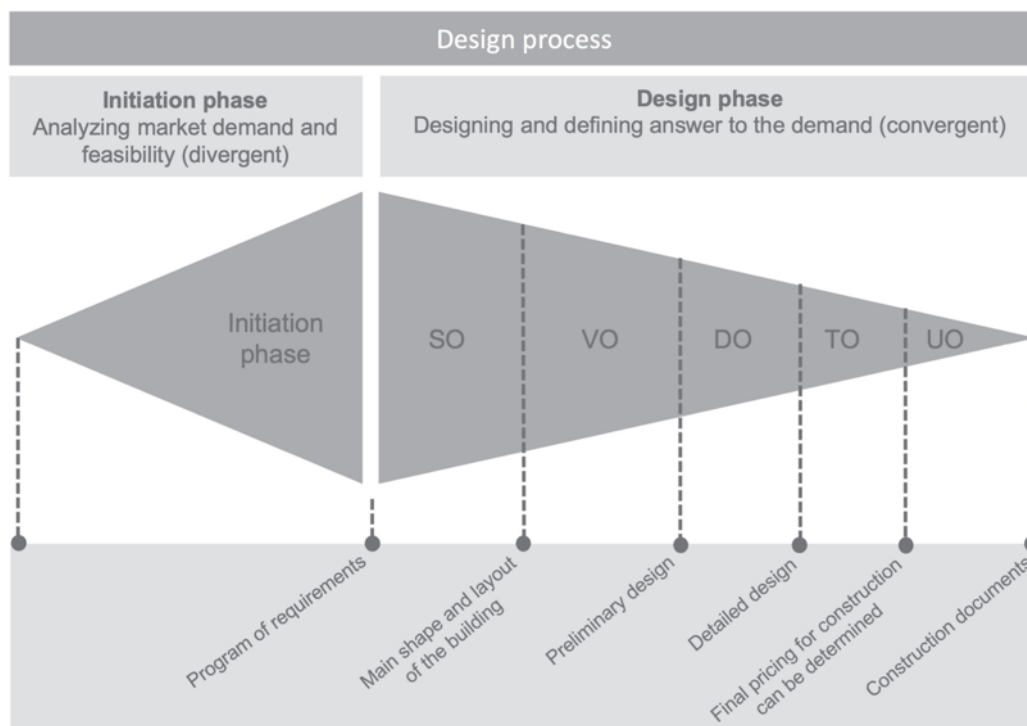


Figure 17 – Design process of a building (own figure, based on Arcadis, 2020a and BNA & NL ingenieurs, 2014)

(Dutch: definitief ontwerp; DO. In this stage, all spatial relations and the materials are determined.

The technical design (Dutch: technisch ontwerp; TO), is more detailed than DO. In this phase, DO will be further developed in order to determine the final pricing for construction (Arcadis, 2020a; BNA & NL ingenieurs, 2014).

In the last stage of the design process the construction documents are developed (Dutch uitvoerend ontwerp; UO). In this stage, details will be added. These documents consist of final design drawings, specification drawings and detail drawings. This will be accompanied by a written part. The construction documents contain will be used by contractors to be able to construct the building. Construction documents are in most cases made by the contractor.

3.7 Circular project management

Two well-known project management frameworks are PMBoK and PRINCE2. Those two frameworks will be briefly explained in the following paragraphs. In the last paragraph, elements which are extra important in circular projects will be explained.

PMBoK is short for Project Management Body of Knowledge, in this book project management activities are described in detail. PMBoK consist of a collection of best practices, techniques and instruments to manage a project. It does not prescribe certain methods or techniques. PMBoK discusses ten management themes. These are scope, time, cost, quality, human resource, communication, risk, procurement, stakeholders, integration, HSSE, and financial (Project Management Institute, 2017).

PRINCE2 is short for PRojects IN Controlled Environments. This framework aims to increase the success rate of a project. The PRINCE2 framework describes 7 principles, 7 themes and 7 processes. The principles are the core of PRINCE2. The seven principles of PRINCE2 are: continued business justification, learn from experience, define roles and responsibilities, manage by stages, manage by exception, focus on products, and tailor to suit the project environment. The themes provide insight on how to control a project, and can be seen as knowledge areas on how to implement the principles. The themes are: business case, organisation, plans, risk, change, and progress. The processes describe a set of activities providing information on how to manage different parts of a project. The different processes according to PRINCE2 are: starting up, initiating, directing, controlling, managing a stage boundary, managing product delivery, and closing a project (Hinde, 2017).

However, there is a difference between circular project management and traditional project management as described by PMBoK or PRINCE2. Some elements in project management should receive more attention. Notwithstanding that the focus points of the project management frameworks are also important for circular

project management. During the design process of a circular building, the design process goes through the same stages as in a non-circular project (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019). In circular project management the following topics should receive extra attention: ambition & people (Architect 1, 2020; Architect 2, 2020; Architect 6, 2020; Client / contractor 3, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020).

3.7.1 Ambition

Setting up ambitions at the start of the project is important to its project success (Project Management Institute, 2017; Hinde, 2017). Especially in regards to a circular project, it crucial to develop a circular or sustainability aim at the start of the project (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019).

A circular office is not the goal, it is a method to reduce environmental impact and create value at the same time. Other ambitions influence possible circular solutions. Therefore, trade-offs should be made. Already in the initiation phase should be determined what the sustainability focus is and how important this ambition is. Ask the following questions; Is the focus circularity, energy, biodiversity, health, social or environment? Do you want to achieve a certificate such as BREEAM, LEED, or WELL? What are the project specific opportunities and disadvantages? What are the preconditions? And can these different aims, opportunities and disadvantages reinforce each other? Formulate the answers in an ambition (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019; Architect 2, 2020; Client 1, 2020; Specialist 1, 2020; Sustainability advisor 1, 2020).

The defined ambition and the preconditions of the project heavily influence the possibilities for circularity within the development project. A circular office can be achieved in different ways. All options have different advantages and disadvantages. As described in paragraph 3.4, four circular themes can be indicated. These themes can help you choose direction. Adaptability could be a suitable direction when it is evident that there will be a building somewhat that size on that location for a long time. Reusability could be suitable when the lifetime is already determined and it is relatively short or in fast changing environments. There are advantages of sustainable material use: decreased environmental impact, characteristic building, sustainability certificate (such as BREEAM). The disadvantage is that sustainable materials are often more expensive. In relation to the process, think outside the box. (Circular) business models, contracts, digital, financing options and other collaboration methods could stimulate circular development.

Ambition

- **Preconditions**
Time, money, scope, quality
- **Sustainability aim**
Circularity, energy, biodiversity, health, social, environment
- **Think outside the box**
(Circular) business models, contracts, digital, financing options
- **Circular focus changes depending on project specific characteristics**
Adaptability, reusability, materials, process

Figure 18 – Take aways from paragraph 3.7.1

3.7.2 People

People make a project. Collaboration is important in a circular building projects, circular success depends on the collaboration with the supply chain. Compared to a non-circular project, dependencies are larger throughout the value chain (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019).

More parties should be involved in the design process and those parties should be involved early on. Change can most easily be realised in the beginning of the design process. Different perspectives and expertise's should be consulted. For example, in the initiation phase or schematic design a workshop can be held to discuss the possibilities for circularity in the project. Possible interesting parties are: client, (sub)contractors, designers (architects, engineers, installation technicians), suppliers, maintenance, demolition contractor, investors, government representatives, specialists (legal, financial, sustainability), and the users (Sustainability advisor 3, 2020; Specialist 9, 2020; Specialist 6, 2020). This broad collaboration can be maintained with different intensities throughout the building process (Adams et al., 2017; Gerding, 2019).

The way people work together has influence in the possibilities for CE in a project. Several authors argue that the right mindset is an important requirement for implementing circularity. That means that people should be enthusiastic about circularity and preferably have experience with circular building projects (Addis, 2006). For project teams non-hierarchical and cooperative organizational structure should be used. This enhances team work and creativity (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019).

Transparency stimulates circularity (Tilman, 2017). Circular construction economy is still in its infancy. Sharing experiences and knowledge is crucial to take it a step further (Tilman, 2017; Adams et al., 2017). Next to that, transparency about the project budget will enhance circularity. Then there is possibility to share risks and openly discuss how the best solutions can be found within the financial budget (Pots, 2018; UKGBC, 2019; Specialist 6, 2020).

As client, you should ask yourself if you want to have a visible sustainable building (lots of green, wood, visible reused products, visible PV panels etc.)? Or do you want a clean and neat office which is nevertheless sustainable? Are there special elements which you would like to reuse in this office? Windows of old train, old employee clothing, parts of the former office of a building already on site, etc. If those questions are answered, the search for suitable materials can start. The search for materials has to start in the beginning of the design process because: there is less certainty in the availability and properties of second-hand materials, and designs which contain an high percentage of reused products are designed with these materials in mind (Architect 2, 2020; Architect 6, 2020).

People

- **Broad collaboration & early involvement**
Client, (sub)contractors, designers (architects, engineers, installation technicians), suppliers, maintenance, demolition contractors, investors, government representatives, specialists (legal, financial, sustainability), users
- **Creativity & teamwork**
Mindset people, non-hierarchical and cooperative organizational structure
- **Transparency**
knowledge and budget
- **Materials**
Search for suitable, second-hand materials and suppliers from the start

Figure 19 – take aways from paragraph 3.7.2

3.8 CE in the Dutch office building sector

The office building sector is part of the utility sector. In the Netherlands there is an office gross floor area of 50 million m². The ownership of those buildings are public organisations, investors or companies which use the building for its own use. Thus, this sector consists of both social, commercial and business real estate (Niessink et al., 2017).

The office building sector is an interesting sector when talking about circularity. This sector deals with a relatively high change rate of ownership and / or users. Moreover, the way we work and use offices is unpredictable and influenced by trends. Therefore, office buildings could benefit extra when they're designed flexible and adaptable. Next to that, the value of a building is strongly related to the rental price. Which depends on the demand. The trends is that companies are willing to pay more for a sustainable office. But is it enough to convince short-term investors? It is still a speculative sector with its fluctuating real estate prices. Long-term investors have more reason to invest in a circular building, namely because of the long-term added value of circular buildings. Moreover, 26 institutional investors with \$ 4.7 trillion assets under management, declared that they want to have a carbon neutral real estate portfolio by 2050 (UNEPFI, 2019). Probably, more real estate investors will follow suit. Circularity could play a major role in achieving this which could lead to increased attention for circular offices.

The biggest difference between buildings and consumer goods is the size and the lifespan, which are both much larger. Moreover, each building project is unique with a great number of stakeholders. In order to demolish or disassemble a building, heavy machinery is needed, and mostly a building is not designed that allows reuse, disassembly or recycling. A typical building will last for 30-50 years, or in some cases much longer. Hence, the owner of the building when designed, is often not the owner when the building is demolished. These characteristics make the building industry a challenge to transform to a circular industry (Adams et al., 2017, Eberhardt et al., 2019; Klein, 2020).

3.8.1 Governmental ambitions and regulations

The attention for CE increases, and earns a place on the political agenda. There are global initiatives and statements of support from international organisations and foundations such as the United Nations. The European Union also promotes CE in the build environment. This is done by developing an assessment tool and plans to incorporate circularity in directives and legislation (European Commission, 2019). The global and European ambitions are in line with the Dutch ambitions. The government-wide program was launched in 2016 which aims to become fully circular by 2050. This program is endorsed by more than 300 social parties (Rijksoverheid,

2016). Part of this program is focused on the Dutch circular built environment. The government has set ambitious goals; in 2030, 50% less primary resources should be used. In 2050 the government wants the economy be fully circular (Rijksoverheid, 2018).

In order to achieve those ambitious goals, certain measures are (to be) taken. A uniform measuring method for circular buildings will be developed. According to plan, the first concept will be presented in 2023. From 2023 onwards, public tenders will be circular as possible. In 2020, a statement will be released in which cases a bill of materials is required. In 2030, all public tenders will be circular by law. The environmental performance requirements will be more strictly. This includes stricter regulation in regards to CO₂. In 2021 the action plan to come to will be presented in order to reduce the carbon emissions to zero in 2050. Next to that, a program will be set up to increase awareness. Moreover, collaborations with the neighbouring countries for circular materials will be initiated. Lastly, the government makes subsidies available to stimulate circular techniques and business models in the construction sector (Ollongren, 2019; Rijksoverheid, 2018).

3.8.2 Current CE practices

Globally, the Netherlands is seen as a frontrunner in the circular economy. The Netherlands is an early adopter of the vision of CE. The Netherlands piloted with Cradle to Cradle buildings. Cradle to Cradle is seen as the predecessor of CE (McDonough & Braungart, 2002; Murray et al., 2017). Consequently, the Netherlands has already implemented leading example projects in the field of circular construction (appendix F).

Inspiring projects are the Global Foods Innovation Centre of Unilever, where 90-95 percent of the materials are reused materials. Moreover, the new Triodos office has incorporated many circular design interventions. In the Netherlands, there are many circular initiatives. However, there is still a long way to close the circle in the Dutch building industry.

3.9 Windows of Opportunity and Multiple Streams Framework

The title of this thesis ‘Windows for Circularity’ refers to the term ‘Windows of Opportunity’ from the Multiple Streams Framework of Kingdon (1987). Windows for Circularity show opportunities for CE during the design process of a building. In this case is the focus on the office building sector. Hereby, facilitating Windows of Opportunity for CE in the design phase of an office building. In the following paragraphs, the Multiple Streams Framework and the idea of Windows of Opportunity will be explained.

3.9.1 Multiple Streams Framework and Windows of Opportunity

Kingdon (1984) created the Multiple Streams Framework. This is a conceptual model to analyse complex decision making. He indicated three streams: the problems stream, policy / solution stream, and a politics stream. The problem stream indicates whether a certain problem receives attention from policy makers and other important stakeholders in that field. The policy stream is triggered when there is a viable solution available to the problem. The politics stream refers to a situation in which there is a motive and opportunity to turn a solution to a policy. If those three streams are aligned, a Window of Opportunity arises. A Window of Opportunity is a fleeting moment in time in which policy change becomes possible. In this short period of time, it is possible to implement new ideas or transitions (figure 20; Kingdon, 1984; Cairney & Jones, 2016; Teisman, 2000).

The Multiple Streams Framework has been frequently used since its publication. Other well-known, conceptual models which focus on decision-making are the phase model and the round model. The phase model focuses on successive and distinctive stages in a process (Teisman, 2000). The rounds model combines the stream model with the phase model. The model focuses on the interaction between the various decisions taken by different actors (Scharpf, 1997; Teisman, 2000). These models can provide insight in the reality and show that decision making has become increasingly complex due to a growing variety of actors, problems and solutions (Kickert et al., 1997).

The concept of ‘decision windows’ can give structure to the complex decision-making process. Decision windows are ‘critical phases in the decision-making process where (sub-)decisions are on the agenda. These windows (..) are Windows of Opportunity for integrating environmental information and values’ (Dalkmann et al., 2003, p. 8). Dalkmann et al. (2003) refer to the Multiple Streams Framework of decision making (Kingdon, 1984). The framework helps theoretically underpin how environmental interests can be integrated in decision-making. Combining these theoretical views, a decision window could be explained as a short period of time in which different interest meet and are combined, or

in which issues are reframed as such that it has become a shared problem with a shared solution (van Stigt et al., 2013; figure 20).

3.9.2 Windows of Opportunity in the building industry

In case of CE in the building industry, it is believed all the three streams are triggered. The impact of buildings on the environment has been indicated as problematic and it is on the agenda (problem stream), there are solutions available from which implementing CE in the industry is a promising one (policy / solutions stream), and there is political endorsement, law and regulations are adapting to stimulate CE in the building industry (politics stream).

However, when looking at a single building level, it is still a challenge to align those three streams in case of the adoption of circular design practices. The involved actors must be aware that the current, linear material flows are harmful for the environment (problem). Possible design solutions must be known (policy/solutions). Lastly, the client must form an ambition which incorporates circularity of the office building and agree on design choices which aim to fulfil these (politics). Currently, this is difficult because it is unclear what all the possible circular design solutions are and when they should be introduced.

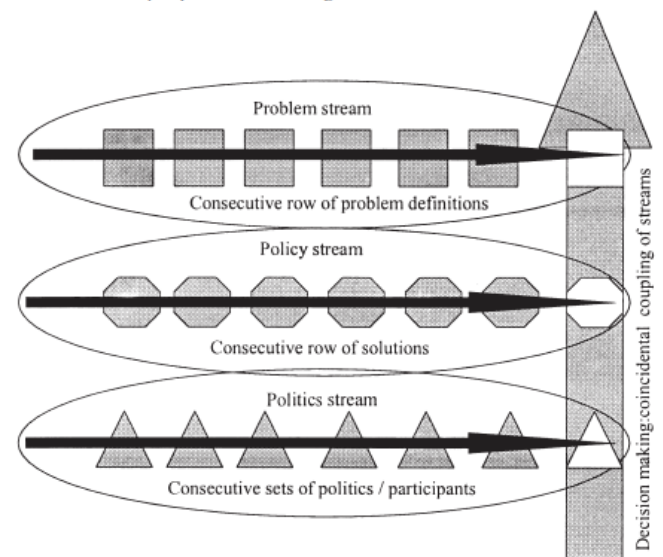


Figure 20 – The concept of decision making in the Multiple Stream Framework (Teisman, 2000)

Summary chapter 3

Chapter 3 discusses the theoretical background of this research. It answers the first sub-question:

How can the circular economy be defined in the Dutch office building sector?

The circular economy presents a new economic system that replace the end-of-life phase with reducing, reusing, recycling and recovering of materials. It is more than just recycling of materials, it is a fundamental systematic change (Kircherr et al., 2017). In the last decades, various circular models have been developed in order to support and explain circularity, yet none of these models are developed specially for the building industry (Raworth, 2017; Stahel, 1982; 1994; 2010; Potting et al., 2017; Ellen MacArthur Foundation, 2017; Bocken et al., 2016; Lüdeke-Freund et al., 2018). The Netherlands is an early adapter of the vision of CE, and has already implemented leading example projects in the field of circular construction in the office building sector (appendix F). Still, also in the Netherlands the implementation of CE in the office buildings sector is in its early stages (Ghisellini et al., 2016; Stahel, 2016).

It is challenging to transform the building industry to a circular industry, because of the characteristics of buildings. Most buildings have a long lifespan, are unique and have to cope with a great number of stakeholders (Adams et al., 2017; Eberhardt et al., 2019; Klein, 2020). The office building sector in particular is characterized with a high change rate of ownership or users, and is heavily influenced by trends and unexpected events. This calls for adaptable and reusable building design. The implementation of circular design could help achieve this.

The starting point of circular design is the notion that buildings are not static but a dynamic system of different layers with different lifespans. Each layer should be refurbished or replaced without damaging the other layers (Graham, 2005; Habraken, 1961; Duffy, 1990; Stahel, 1982). When talking about circular construction, four topics regularly arise in literature and in practise. These topics are adaptability, reusability, materials, and process. Regarding the design process of a building, the process consists of six stages: initiation phase, schematic design, preliminary design, final design, technical design and construction documents (in Dutch: initiatieffase, SO, VO, DO, TO, UO). Throughout this process, the design of an office become increasingly detailed (Arcadis, 2020; BNA & NL ingenieurs, 2014).

The title of this thesis 'Windows for Circularity' refers to the term 'Windows of Opportunity' from the Multiple Streams Framework of Kingdon (1987). A Window of Opportunity refers to fleeting moment in time when different streams are aligned; the problem, policy / solution, and politics stream (Dalkmann et al., 2003; Kingdon, 1984). Windows for Circularity show opportunities for CE during the design process of an office building. Hereby, facilitating Windows of Opportunity for CE in the design process of an office building.

4 Methodology

4.1 Introduction

This chapter discusses the research design. It explains the research approach, the research method, the used data gathering methods and the correlating data quality control measures. Lastly, the thesis planning will be shortly discussed.

4.2 Research approach

A design-based approach is chosen because it fits the characteristics of the research problem, objectives and questions. Design-based research is simultaneously committed to providing theoretical contributions and practical solutions (Herrington et al., 2007).

This study applies a qualitative research approach. This type of research is suitable when there is lack of empirical evidence, or knowledge (Fellows & Liu, 2015, p. 9). Therefore, it matches the context of this study. Qualitative research is descriptive and focuses on the knowledge which can be gathered through people, reference projects and literature (Fellows & Liu, 2015).

It is not the aim of this study to do predictive research and test and refine hypotheses, which is rather

the aim in qualitative research (Baarda, et al., 2013). This research aims to create insight in CE possibilities in the office sector by gathering information from literature, reference projects, and knowledge of people. The characteristics of this research are more in line with design-based research. According to Brown (1992) and Collins (1992), design-based research is suitable for research that, 1) addresses complex problems in real context in collaboration with practitioners. 2) Integrates known and hypothetical design principles with technological advantages to develop plausible solutions to these complex problems. 3) Conducts reflective research to test and define new design principles. Those three characteristics are found in this research. The problem addressed in chapter 1, is complex and interwoven with practice. The objective is to create a tool based on known principles and hypothetical design principles (literature, practice). This results in a plausible solution for the complex problem with the help of technological advantages. The development of such model is best done in a reflective and iterative way, which is supported by a design-based research approach (Brown, 1992; Collins, 1992; Herrington et al., 2007; Reeves, 2006).

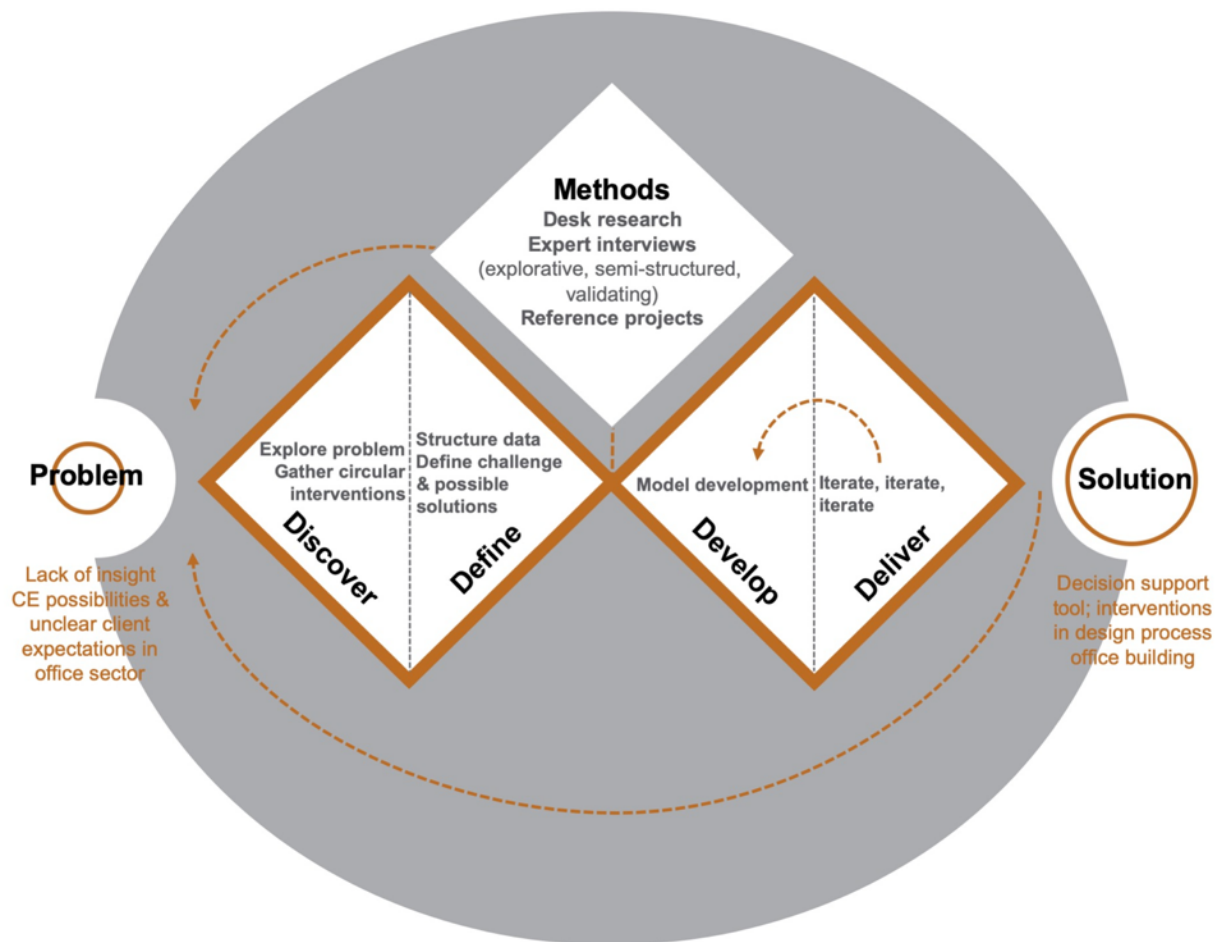


Figure 21 – Research design (own figure, based on the Double Diamond method of the Design Council (2007, 2019))

4.3 Research method

In order to answer the research questions, a design-based research is used. There are multiple design-based research methods. In this research is a Double Diamond method applied, a method developed by the British Design Council. This method is suitable for problems which are socially, economically and environmentally challenging. The Double Diamond method adapted for this research is visually presented in figure 21.

The method consists of two stages and four phases. The stages are the two diamonds. The first one focuses on defining the problem, gathering information and defining the aimed result. First a discover phase, where the problem will be explored more widely. This helps to understand, rather than assume, what the problem is. The second phase is focused on action (convergent thinking). In this phase called 'define', the challenge and possible solution directions will be defined.

The second diamond focuses on the development of aimed result in an iterative way, in this case a decision support tool. The third phase is again a phase when possibilities and the problem will be explored further (divergent thinking). In this phase, a draft solution to the problem will be designed. The last phase involves the testing and validating of the solution in an iterative process. Finally resulting in a research outcome.

This is not a linear process as the arrows in figure 21 show. It could be true that through research a deeper issue will come up, and requires to go back to the beginning. This research method is iterative at its core (figure 21; Design Council, 2007; Design Council, 2019).

4.4 Data gathering

Different methods of data gathering are used during this research, such as desk research, expert interviews and reference projects. According to the stage and phase of the research, different data gathering methods will be used. Figure 21 is a visual representation of the research method. Research stage I, is the first diamond and exists of the phases discover and define. Research stage II is the second diamond and exists of the phases develop and deliver. Table 4 explains the focus of this research in each phase of the Double Diamond method by means of questions. Next to that, the data gathering methods and used mode of thinking and involved perspectives are shown in this table.

In the following sections is explained why these research methods are used and when and how which data gathering methods are used.

4.4.1 Discover & define (research stage I)

The first research stage focuses on the exploration of the problem and defining a solution direction. The data gathering methods which are used in this first stage are; desk research, explorative and semi-structured interviews, and reference projects.

Desk research

To get insight in this practical problem, literature research should be combined with the practitioners' perspective. Desk research is necessary to build the theoretical framework and support the field research (Reeves, 2006)

Exploratory interviews

Exploratory interviews should have a theme (Kvale, 2008). This means that the purpose of the interview should be clear. During this research, exploratory interviews were held in order to explore and define the problem which was needed to be solved, and the characteristics which are needed for the solution (in this case the decision support tool). Practically, that meant that the interviews were focused on the barriers of the implementation of CE in the building sector, and the possible enablers which could support the transition to a circular built environment. Even though exploratory interviews do not require a predetermined set of questions, interviews were prepared around this theme and the expertise of the interviewee to ensure relevant information was gathered (Kvale, 2008). In design based research, good insight in the practical and theoretical problem is of the utmost importance (Reeves, 2006). Desk research provided the insight in the theoretical problem, the exploratory interviews provided insight in the practical problem. The exploratory interviews were held with different people. Mainly from Arcadis or the TU Delft. The list of experts which were interviewed during the exploratory interviews is shown in table 3. Extra explanation about the content of the interviews is given in appendix C.

Semi-structured interviews

Semi-structured interviews employ a blend of open and closed questions, often accompanied by follow-up why or how questions. This data gathering method is suitable for problems as stated in this research. The complexity and ambiguity call for an in-depth research approach such as interviews (Adams, 2015; Baarda et al., 2013). Semi-structured interviews are used in this research stage to obtain more in-depth data in comparison to the exploratory interviews.

The questions in the interviews were not leading or offensive. The first questions after the introduction were closed questions. This is done to ensure that both parties know that they are talking about the same subject. The largest part of the interview are open questions which stimulate descriptive answers and knowledge sharing (Kvale, 2008). The interview template is presented in appendix D. The semi-structured interviews were held in order to identify the most impactful and common circular interventions and when these circular interventions could be introduced in the design stage of an office building. These were gathered and analysed. Based on the interview template (appendix D), knowledge about circular interventions and their placement in the design process

was gathered systematically. As shown in the appendix E, the interview results, some interventions are based on the expert knowledge of certain specialists and some are broadly supported among the interviewed experts.

Multiple perspectives are relevant for this research. That of an architect, a client, a contractor, sustainability advisor, or specialist. Because multiple perspectives are relevant in order to develop a tool which support circular decisions in the design phase of an office building, multiple perspectives are taken into account in this research.

The right number of interviewees is not fixed and hard to determine (Kvale, 2008). Due to time constraints, the focus is on experts in the topic or people with extensive interaction with the topic at work. A minimum of one interviewee per perspective is maintained. In stage one, the perspective of the architect, client and contractor are considered. Moreover, knowledge from sustainability advisors and specialists is used to gather the needed information for the decision support tool. Table 3 shows the interviewed experts in stage 1. The full list of interviewed experts and more information about their expertise and accomplishments is given in appendix C.

	Perspective	Expertise	Company type
Exploratory interviews	Architect 1	Circular design	Architect
	Specialist 1	CE & area development	University
	Specialist 2	Architect network	Institution
	Sustainability advisor 1	Cost & sustainability	Engineering & consultancy
	Sustainability advisor 2	Circular economy concepts	Engineering & consultancy
Semi-structured interviews	Architect 2	Circular design	Architect
	Client / contractor 1	CE & financial implications	Engineering & consultancy
	Client / contractor 2	Circular interior	Engineering & consultancy
	Client / contractor 3	Project management BREEAM	Engineering & consultancy
	Specialist 3	(Sustainable) concrete	Consultancy
	Specialist 4	CE materials & LCA	University
	Specialist 5	Real estate market	Engineering & consultancy

Table 3 – Interviews stage I (more information about interviewees in appendix C)

Stage	Phase	Question(s)	Data gathering method	Mode of thinking
1	Discover	- What is the problem? - What is the needed background information? - How can the circular economy be defined in the Dutch office building sector? (SQ1)	- Desk research - Explorative interviews - Reference projects	Divergent mode to explore problem, define problem and gain insight in the situation and existing knowledge
	Define	- What is the aimed result? - How to design a decision support tool which helps to grasp opportunities for the circular economy in the design phase of an office building? (SQ2)	- Desk research - Semi-structured interviews - Reference projects	Convergent mode to structure data and define aimed result
2	Develop	- How can the tool support circular decisions? - Within each stage of a design process, what are the circular interventions in the development of an office building? (SQ3)	- Creative methods - Semi-structured interviews - Reference projects	Divergent mode to study different options to present research findings in a tool
	Deliver	- Have we done it right? - In what way could the developed decision support tool be used and implemented in the office building sector? (SQ4)	- Validating interviews - Participatory validating workshop	Convergent mode to iterate, and develop the most suitable way to visualize and use the model

Table 4 – Content and data gathering methods per research phase Double Diamond method

Reference projects

Reference projects will be used as well. Reference projects are superficial case studies. This research does not require in-depth case study research. It uses reference projects to gather practical examples of circular interventions. It does not look at all the factors that play a part in a particular case, but it looks at a relatively large amount of cases.

For practice-oriented research, reference projects or case studies are exceptionally well suited. While conducting this research, knowledge from practice is required. Therefore, the circular interventions are gathered, among others, through reference projects (Verschuren, et al., 2010; Fellows & Liu, 2015).

All these reference projects have at least one implemented circular intervention and are preferably office buildings. These common characteristics minimize the external variables which could influence the outcome (Flyvberg, 2006; Fellows & Liu, 2015).

In this research, reference projects are used to gather suitable and practical examples of circular interventions in office buildings. These will be used to gain better technical understanding of circular interventions in the office building sector, and make the decision support tool practical by giving examples.

The list of reference projects is given in appendix F. This table explains the reference projects, the circular interventions which are studied from the reference projects, relates the reference projects with the circular themes, and gives the sources for the reference projects.

4.4.2 Develop & deliver (research stage II)

In the second diamond (stage II) there are two phases, develop and deliver. This phase is about the development of the decision support tool and the validation of it. In the first stage the needed information to develop such a tool was gathered. In the second stage, the pieces came together in an iterative way. The data gathering methods used in this stage were; design thinking, semi-structured interviews, a workshop, reference projects, and desk research.

Desk research

In the first stage, desk research was used for gathering information and compare practical observations with literature. Resulting in a strong academic foundation of the research. Desk research can also be used in qualitative research to validate preliminary research results (Fellows & Liu, 2015). In the second stage, desk research focused on validating the research outcomes and testing the validity of the decision support tool

Semi-structured interviews

Semi-structured interviews in stage II are held to improve the concept decision support tool which is created in the develop stage. As in stage I, multiple experts with different perspectives are interviewed. Most semi-structured interviews are used in the same way as in stage I and used

the same interview template (appendix D; Kvale, 2008) or are focused on the specialist expertise of the interviewee. The difference is that in the semi-structured interviews of research stage II, the depth of the interviews was greater. These interviews evolved around specific cases or interventions. This was due to the fact that more prior knowledge was gained and interviewees were sometimes chosen for their specific knowledge that could fill gaps in the decision support tool.

Validating interviews and workshop

Some interviews were held in order to validate the decision support tool. Validating research is necessary for the verification and validation of the result. This is done by expert feedback and model testing (Kvale, 2008; Baarda et al., 2013).

Moreover, a workshop is held to test the model. This was an online meeting with 11 Arcadis employees from the team of project managers from the building department. The workshop was designed to test the model and receive feedback in a short amount of time. All attendees received the same background information and were stimulated to interact (Baarda et al., 2013).

The research and decision support tool were introduced in the beginning of the workshop. Followed by an interactive online brainstorm session in two groups. A case was introduced and they were asked to generate ideas to increase the level of circularity of this office building alongside the decision support tool. At the end of the workshop, the two groups presented their findings to each other. There was time to discuss it and also discuss the usability of the tool. This workshop was meant to validate the usability of the decision support tool by testing it.

Reference projects

In stage II, reference projects are used similarly as in stage I. However, in stage I the focus lies on discovering different practical examples of circular interventions and defining when they were introduced in the design process. In stage II, reference projects are used to find practical examples of circular interventions which are still missing the decision support tool. Moreover, reference projects are used in validating the tool. Testing the tool on real life cases.

Creative methods

In the third phase, the 'development' phase, creative methods were introduced. This was done in order to be able to develop a tool based on the input from research stage I. Research methods such as fast visualization (generation quick idea sketches), and brainstorming were used. This was an iterative process where the decision support tool was continually changed and improved.

(Design Council, 2007; Design Council, 2019).

	Perspective	Expertise	Company type
Semi-structured interviews	Architect 3	Circular design	Architect
	Architect 4	Circular design	Architect
	Architect 5	Circular design	Architect
	Contractor 1	Circular development	Contractor
	Client 1	CE & procurement	Government
	Client / contractor 4	Sustainable development	Engineering & consultancy
	Specialist 6	Real estate investment & CE	Bank
	Specialist 7	CE & installations	Engineering & consultancy
	Specialist 8	CE & law	University
Validating interviews	Specialist 1	CE & area development	University
	Sustainability advisor 2	Circular economy concepts	Engineering & consultancy
	Architect 6	Circular design	Architect
	Specialist 9	CE & architects	Institution
	Sustainability advisor 3	Integral CE design solutions	Consultancy
Validating workshop	Client / contractor 1, 4-13	Project management. Specializations of individuals given in appendix C	Engineering & consultancy

Table 5 – Interviews stage II (more information about interviewees in appendix C)

4.5 Data quality control

The collected data must ensure validity (internal and external), and reliability. Internal validity is the accurate translation of the collection data into conclusions. The external validity is about the translation of the conclusions from the research into a wider context. External validity is also referred to also generalizability. The reliability of a research refers to the replicability of a research. Reliability, as well as internal and external validity must be considered throughout the research process (Fellows & Liu, 2015).

There are some key challenges in this research in regards of data quality control. These are the small scale, observer bias, external variables and alternative explanation. A short explanation of these threats to the quality of the research will be given in the next paragraph, followed by the planned mitigation measures.

4.5.1 Data quality control challenges

Firstly, this is a small-scale research. Due to time and resources constraints of this research, it is not a large-scale research. Follow-up research is necessary to build onwards the findings in this research and improve the external validity. Secondly, observer bias is a known quality threat in research. Since all studies which involve people are to a certain extent influenced by the background of those people, observer bias should be considered by the interpretation of the results (Fellows & Liu, 2015). Thirdly, CE in the built industry is highly dynamic and complex. This result in a dynamic and complex context of the area of research. Especially, while studying reference projects, the context could affect project outcomes (Fellows & Liu, 2015). Lastly, it is difficult to rule out alternative explanations because the results are based on interpretation (Fellows & Liu, 2015). This affects the internal validity of the research.

4.5.2 Mitigation measures

To enhance the credibility of the research, triangulation was applied for data collection. The term triangulation refers to the practice of using multiple sources of data. Triangulation aligns multiple perspectives and hence, leads to a more comprehensive understanding of the area of research. According to Fellows and Liu (2015, p.30), triangulation can be achieved in several ways. Examples are the comparison of collected data from different resources, and revision of the work by multiple researchers. As explained in paragraph 4.4, multiple sources were used to gather the data, including desk research to assess the state-of-the-art literature, exploratory, semi-structured in-depth interviews and reference projects. Moreover, next to the main researcher there are two supervisors, a professor, and a practitioner involved in the revision of this research. This triangulate approach contributes to data quality control because it supports all three aspects of a credible research; reliability, internal, and external validity.

Strategic sampling, as meant strategic choice of interviewees and reference projects, are crucial in order to maintain external validity. In regards to reference project selection, projects shall be chosen which have relatively similar key characteristics. The list of chosen reference projects is given in appendix F. What all these reference projects have in common is that they all have implemented circular interventions in the design phase and most of the buildings have an office function at completion. This minimizes the external variables which could influence the outcome (Flyvberg, 2006; Fellows & Liu, 2015).

A design-based research includes an iterative process. The iterative process has built-in checks and improvements by other researchers, practitioners, and literature. This improves the reliability and the internal validity of the research (Reeves, 2006).

Summary chapter 4

Chapter 4 discusses the used methodology in this research. It answers the second sub-question:

How to design a decision support tool which helps to grasp opportunities for the circular economy in the design process of an office building?

The aim of the methodology is to describe how to design a decision support tool which helps to grasp opportunities for the circular economy in the design process of an office building. Thus, help create Windows of Opportunity. In order to do so, the Double Diamond method is chosen. The Double Diamond method is a design-based research approach. It is in line with the characteristics of the addressed research. The research has to cope with a lack of empirical evidence and addresses a complex problem in collaboration with practitioners. Information is gathered from literature, case studies, and knowledge of people (Fellows & Liu, 2015; Brown, 1992; Collins, 1992; Reeves, 2006; Herrington et al., 2007; Design Council, 2019).

Figure 22 is a visual presentation of the methodology of this research. It shows from left to right the successive steps of the Double Diamond method. Starting with the problem, then the phases and its focus, ending with the aimed solution. The squares above the diamonds show the used data gathering methods and where they will be used for. The arrows show that it is an iterative process which leads to the development of a solution.

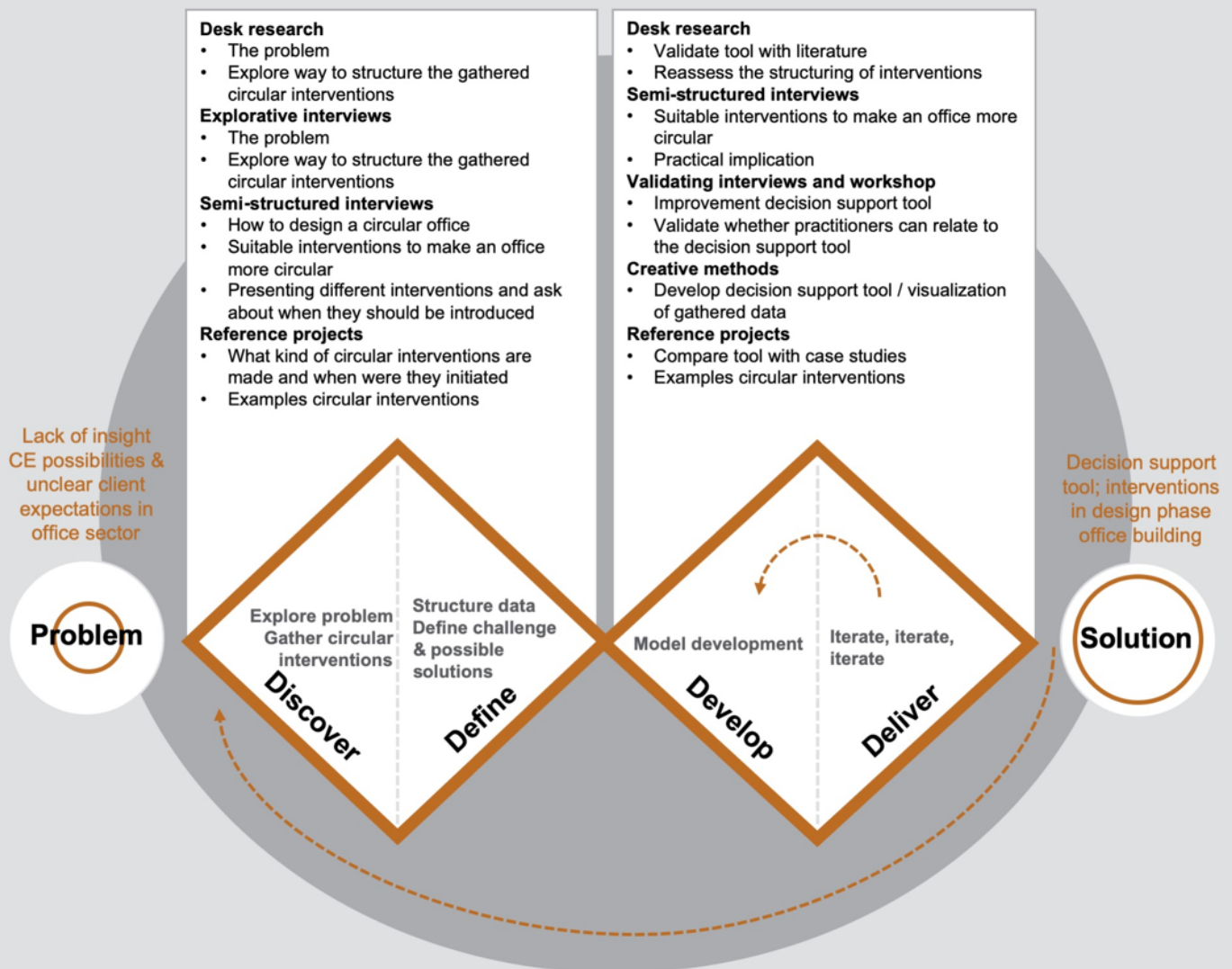


Figure 22 – Double Diamond method applied for this research

5 Results

5.1 Introduction

This chapter presents the research findings. Paragraph 5.2 describes the aimed result, namely the decision support tool. Paragraph 5.3 explains why the tool looks like it does. In paragraph 5.4 will be explained how the decision support tool should be used. Paragraph 5.5 till 5.10 provides the explanation of the circular interventions named in the tool.

5.2 Aimed result

The aim of this research is to develop a decision support in order to facilitate the decision-making process towards a circular office. It provides insight into the various circular interventions which can be taken in the different stages of the design phase of an office building. The requirements of such tool are:

- The tool should be based on all key principles of circular buildings
- The tool should include practical examples (interventions) based on established circular strategies and couple them to the design stage in which they best be introduced
- The tool should be non-static, because circularity is a relatively new topic, and is still in development
- The tool should be user-friendly and comprehensible for designers, clients, and non-experts to CE in the built environment. Hence, be visually attractive and easily accessible

5.3 Explanation structure decision support tool

The decision support tool consists of a frame (figure 26). The structure refers to the building layers, four circular themes, and the different phases in a design process. This study also provides an filled in version to inspire its users with examples of circular interventions (figure 27). The following paragraph elaborates further on the structure of the tool.

There is deliberately chosen to prominently incorporate the building layers of Brand (1994) in the circular decision support tool. The building layers do not represent a building as one product, but as a system with interconnected sub-systems. All the six layers have a potentially different lifespan. The average lifespan of a complete building is 60 years (Reyna & Chester, 2015). Yet, some buildings have substantial longer or shorter lifespans. The lifespan is influenced by the location, aesthetics, and quality of the building, and the lifespan is influenced by technical failures or new regulations. However, not every building layer ages at the same time. If a building is able to adapt its different layers separately, it will prolong the complete lifespan of the building and avoid demolishing of parts which are still functioning (Castro & Pasanen, 2019; Brand, 1994; Graham, 2005; Habraken, 1961).

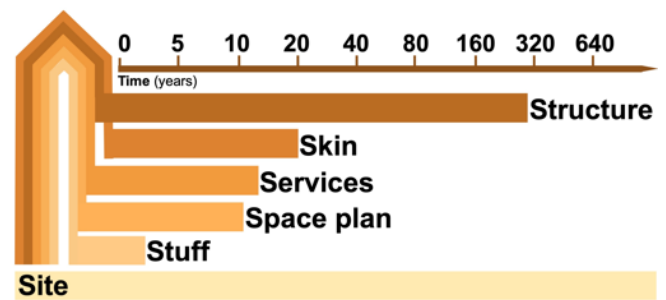


Figure 24 – Building layers (own figure based on Brand (1994))

The different phases in the design process play a major role in the decision support tool because it indicates when certain interventions could be best introduced. Each stage has different tasks and deliverables as described in the DNR standaardtaakverdeling (BNA & NL ingenieurs, 2014; figure 25). The DNR standaardtaakverdeling is the most broadly used design process description in the Netherlands. This design process description is discussed in chapter 3.6.3 and explained in the legend (figure 28). Some interventions could be introduced in an earlier or later stage than clarified in the tool. This depends on the project itself. However, the interventions are placed on the timeline according to the interviewed experts and looking at earlier projects. Therefore, it gives insight in when Windows for Circularity are open.

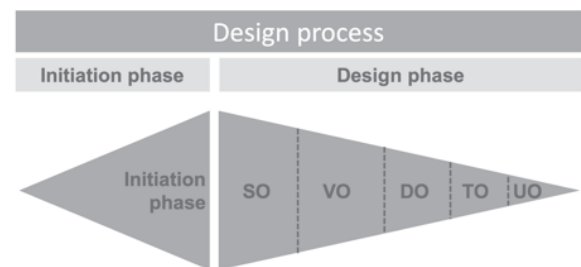


Figure 25 – Different stages in the design process (BNA & NL ingenieurs, 2014)



Figure 23 – Circular themes

To increase the readability of the tool, the circular interventions are grouped into different circular design themes (figure 23). Each intervention has a different theme. The themes are based on an extensive literature review and confirmed in the interviews. The meaning of these themes is explained in the legend (figure 28).

5.4 Reading guide decision support tool

Figure 26 presents the framework of the decision support tool without circular interventions. On the Y-as the different layers of a building are shown, on the X-as the stages of the design process are shown. The full-coloured boxes indicate that in these stages the decisions related to those building layers are made. In the initiation phase, no layers are presented because then all layers need to be discussed in regards to circularity.

An overview of possible interventions in the stages are shown in figure 27 and explained in the paragraphs 5.6-5.10. Each paragraph corresponds to a stage and the circular interventions are explained top-down. In every stage there are multiple possible interventions. These are categorised in themes and in the building layer where they respond to. The explanation of the themes, layers and design stages are given in the legend (figure 28).

The circular decision support tool is a support tool. It is not a roadmap that provides all the needed steps to be taken in order to design a circular office. The tool indicates which layers are important in what stage of the design process. Next to that, the filled in version provides inspiration into the possibilities on how to achieve a circular office. Not all circular interventions are suitable for each project, and there will always be project specific circular interventions. Therefore, the listed circular interventions in the tool are not exhaustive. Circular economy in the building industry is a fast-developing field of research. Hence, the listed circular interventions should be regularly updated. Be that as it may, the current list of

possible circular interventions (paragraph 5.6-5.10) provide a solid overview of the current possibilities.

The tool can be used by designers and clients in different stages of the design process for different purposes. For the client it can serve as an exploratory guide to circular design strategies and learn from different examples. It helps them to better understand what circularity entails in the office building sector. For architects it can also be an exploratory guide but it can also support in making the circular design choices, because it helps identify specific design-choices based on their characteristics and most suitable design stage.

The circular decision support tool should be used from the initiation phase till construction documents. It explains the reader what has priority in which stage of the design process. In the beginning of the design process, the tool functions merely as a brainstorm tool. In those stages it is beneficial to have an overview and have practical examples. In later stages, the function changes to merely an evaluation tool. Then its added value is to help reflect whether circular ambitions are achieved. An example of how the decision support tool can be used is given in appendix G.

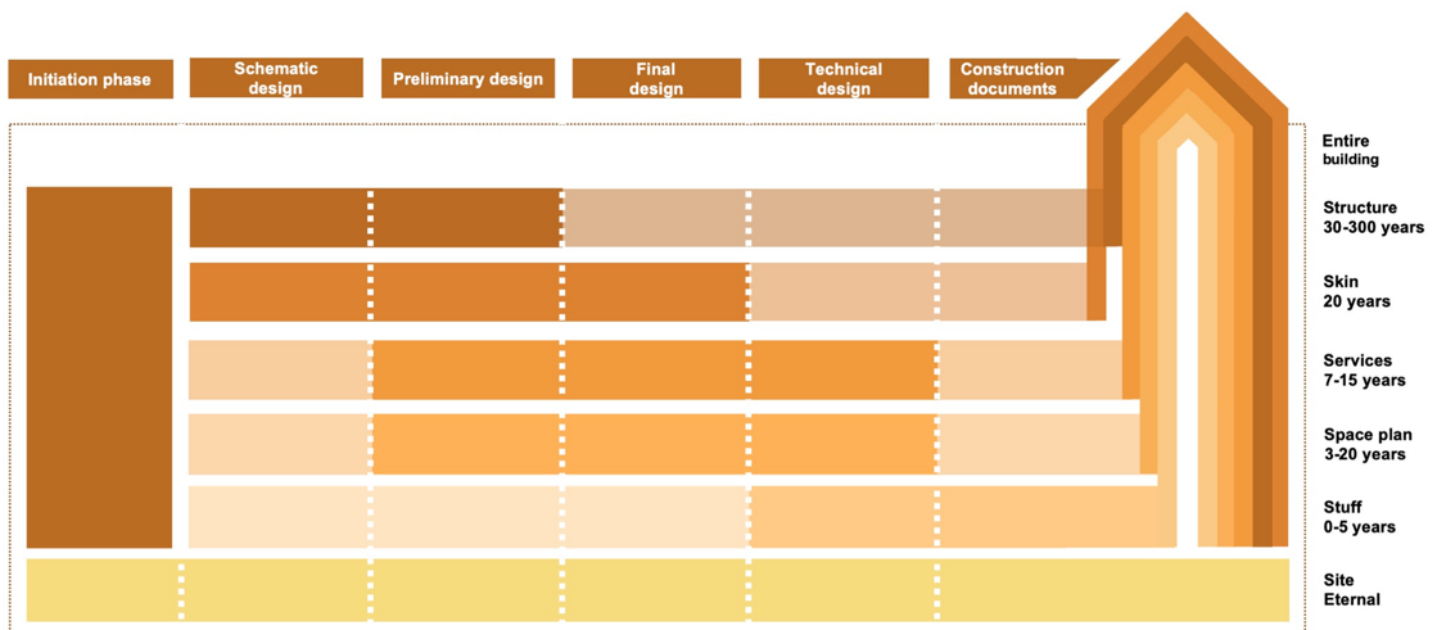


Figure 26 – Windows for Circularity, a decision circular support tool (the framework without filled in circular interventions)

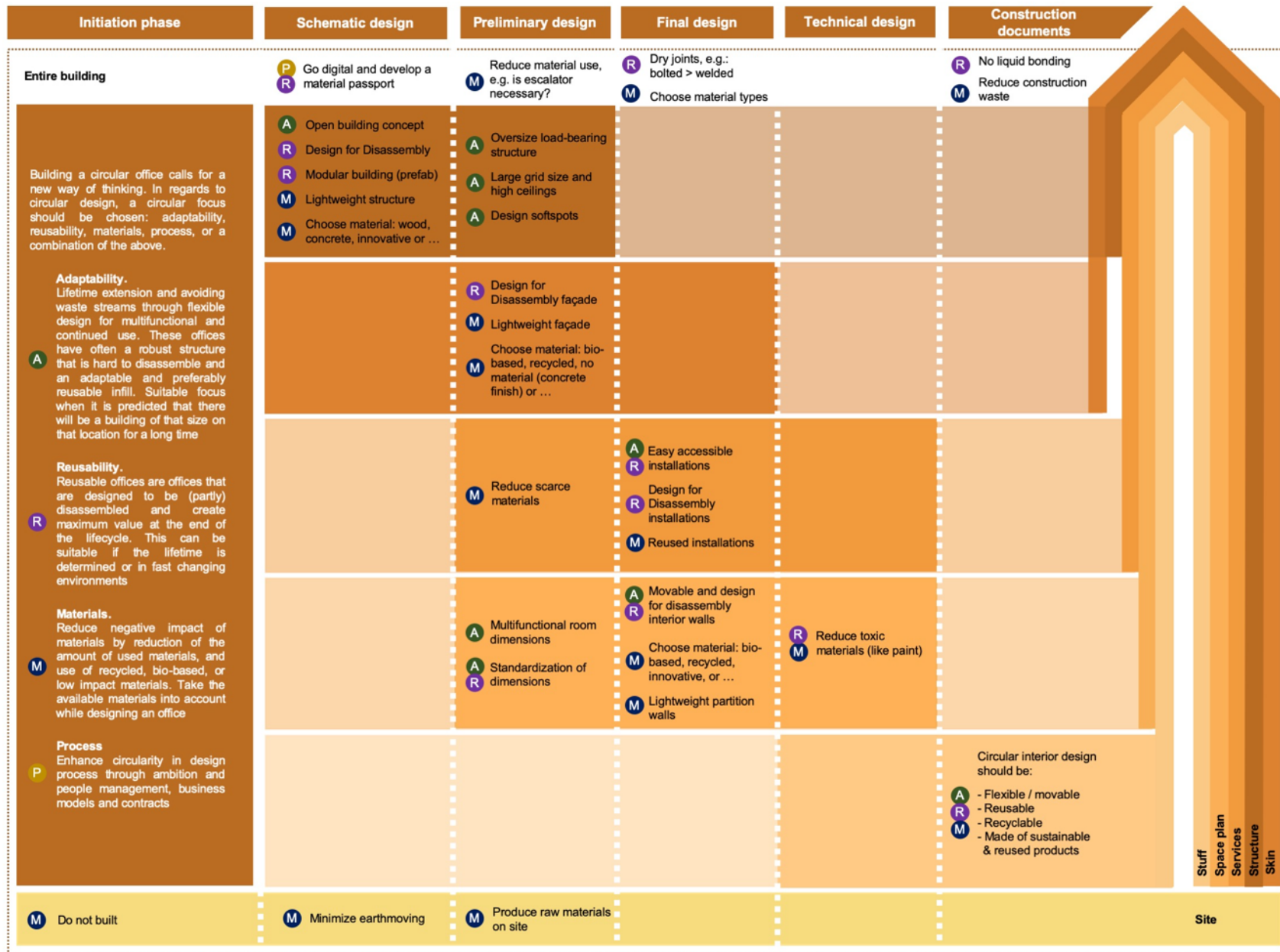


Figure 27 – Windows for Circularity, a decision circular support tool (with circular interventions)



Figure 28 – Legend Windows for Circularity, a decision circular support tool (with circular interventions)

5.5 Interventions initiation phase

Implementing circular economy principles into your project calls for a new way of thinking. In order to reach the full potential of circular design, this should receive attention already in the initiation phase. Starting with clear ambitions and managing the stakeholders.

Ambition

Setting up ambitions at the start of the project is important to its project success, and these ambitions should be managed throughout the process. Especially in regards to a circular project. Other ambitions influence possible circular solutions. Therefore, trade-offs should be made. When developing an ambition, think about the following topics

- **Preconditions**
Always keep the preconditions in mind when developing an ambition: time, money, scope, quality
- **Sustainability aim**
Is the focus circularity, energy, biodiversity, health, social? Do you want to achieve a sustainability certificate?
- **Think outside the box**
(Circular) business models, contracts, digital, financing options. For instance, if the office building decreases absenteeism, a larger budget may come available.
- **Circular focus changes depending on project specific characteristics**
A circular office can be achieved in different ways. Adaptability, reusability, materials, process

(Project Management Institute, 2017; Hinde, 2017; Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019; Architect 1, 2020; Architect 2, 2020; Client 1, 2020; Contractor 1, 2020; Specialist 1, 2020; Sustainability advisor 1, 2020).

People

People make a project. Collaboration is important in a circular building projects, circular success depends on the collaboration with the supply chain. Compared to a non-circular project, dependencies are larger throughout the value chain. Therefore, in a circular process attention is required for the following topics:

- **Broad collaboration & early involvement**
Different perspectives and expertise's should be involved early in the design process. Possible interesting parties are: client, (sub)contractors, designers (architects, engineers, installation technicians), suppliers, maintenance, demolition contractor, investors, government representatives, specialists (legal, financial, sustainability), user (Adams et al., 2017; Gerding, 2019; Sustainability advisor 3, 2020; Specialist 9, 2020; Specialist 6, 2020)

- **Creativity & teamwork**

The way people work together has influence in the possibilities for CE in a project. Several authors argue that the right mindset, teamwork and creativity is an important requirement for implementing circularity (Addis, 2006; Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019).

- **Transparency**

Transparency stimulates circularity. Circular construction economy is still in its infancy. Sharing experiences and knowledge is crucial to take it a step further. Next to that, transparency about the project budget will enhance circularity. Then there is possibility to share risks and openly discuss how the best solutions can be found within the financial budget (Tilman, 2017; Adams et al., 2017; Pots, 2018; UKGBC, 2019; Specialist 6, 2020)

- **Start search for suitable, second-hand materials early**

The search for materials has to start in the beginning of the design process because there is less certainty in the availability and properties of second-hand materials, and designs which contain an high percentage of reused products are designed with these materials in mind (Architect 2, 2020; Architect 6, 2020; Architect 7, 2020)

Don't build

The first questions that should be asked is: How much office space is really necessary? Why do you need that space? What is the function of the desired building? Can that demand be fulfilled in a different way? Can we share services? Can we refurbish an old building? Could we work more from home? Can we optimise our office space? Do we need office space or do we need something else? Try to avoid building something that actually is not necessary (Architect 1, 2020; Architect 7, 2020; Client / contractor 2, 2020; Sustainability advisor 1, 2020).

Sustainability starts with questions like these. The most sustainable office ever built, is the one that was never built.

5.6 Interventions schematic design



Go digital and develop a material passport

Office design in digital system with BIM. Information can be added during the design process. This can be integrated with a material passport.

- + This information makes it easier to disassemble the building and reuse its parts and materials
- + Maintenance of an office with a digital twin or an updated BIM model with material passport, is easier, cheaper and has a lower failure rate
- The material passport costs time and needs to be updated during its lifetime
- Investor of the office might not be the owner of the office and the building price does not reflect the added building value of the digital model

(Architect 6, 2020; Architect 7, 2020; Client / contractor 8, 2020).



Figure 29 – Material passport can be integrated in BIM and creates the necessary transparency for a circular economy in the built environment

A Open building concept

John Habraken developed the idea of an open building (1963). He distinguishes two systems, the resilient and robust structural framework and the reusable, renewable or recycled infill systems. The infill systems contain facades, interior walls, fixed furniture and technical installations. All are designed for disassembly and have standard dimensions, in that way the infill systems can be used in entirety in a new building with or without some desired alterations.

The interest in this system increases all over the world. In Japan there are already more than a million open dwellings, those people can take their home (thus their infill system) to a new building.

- + Extended lifespan of building due to adaptability
- + Suitable for co-creation, more influence for user
- Only effective as multiple buildings adapt this system and use the same standard dimensions
- Structure is not flexible

(Architect 1, 2020; Architect 7, 2020; NEXT21; Habraken, 1961, 2003; Cao et al., 2018).



Figure 30 – Next21, an experimental housing development using open building principles in Osaka, Japan. Designed by SHU-KO-SHA in 1994

R Design for Disassembly load bearing structure

When Design for Deconstruction is applied, a building can be completely disassembled, including the load bearing structure. This is in line with the concept of Design for Disassembly (DfD). DfD aims to design buildings that are meant for value recovery after its lifetime. When designing for disassembly, you ask yourself the question: 'How can this building and all its parts be reused at the end of its first useful life?' A modular building is an example of a building which is designed for disassembly.

- + Extended lifespan of building due to adaptability
- + Suitable for co-creation, more influence for user
- Only effective as multiple buildings adapt this system and use the same standard dimensions
- Structure is not flexible

(Architect 1, 2020; Architect 2, 2020; Architect 3, 2020; Contractor 1, 2020; Sustainability advisor 3, 2020 Sustainability advisor, 2020; City Hall Venlo; Durmisevic et al., 2019).



Figure 31 – City hall Venlo. It is designed by Kraaijvanger Architects according to C2C principles. The building has, among others, a complete demolition plan on how materials can create maximum value after use

R Modular building (prefab)

Modular buildings are prefabricated buildings that consist of repeated modules. The different modules (can be working spaces, offices, canteens, etc.) are connected with inter-module connections. The modules can be easily disassembled from each other and preferably the module itself is designed for disassembly. Steel frames are used to achieve high- and mid-rise modular buildings.

- + Fast construction (less work on site)
- + Low waste during the construction
- + Flexible and easy reusable building
- + Much developments and quality improvements in modular and prefab buildings
- Logistics of modules from factory to site is difficult
- Restricted flexibility, standardised module sizes can be restricting
- Past performance and perception (perceived lower quality or perceived poorer overall aesthetic quality), can lead to lower valuation building

(Architect 5, 2020; Architect 7, 2020; Client 1, 2020; Amsterdam International Community School (AICS); Guy & Ciarimboli, 2008; Yu et al., 2013).



Figure 32 – AIC School. This 100% modular building supposed to be finished in 2020 and be disassembled and reused 5 years later. Designed by BurtonHamfelt Urban Architecture

M Lightweight load bearing structure

There are two options to design a light load bearing structure: slim construction and design with light materials.

Slim construction. There is a trade-off between the strength of the material and the amount of used material. In other words, the amount of used wood, or in case of concrete the percentage cement and steel. The option with the least environmental impact, is the best.

Design with light materials. An example is foam cement, a mixture of styrofoam and cement in combination with steel. Foam cement is lightweight with low thermal conductivity and it can be partly made from recycled styrofoam. Currently, it is mostly used in housing and southern Europe (Architect 5, 2020; Sustainability advisor 1, 2020; Hoffman, 2017).

- + Right trade-off between the characteristics of a material and the amount of material used result in the least environmental impact
- + Lightness materials result in cheaper and more energy efficient transport
- + There are many developments in lightweight 3D printing of for instance concrete
- The most environmentally friendly option is not always the most aesthetic or affordable one

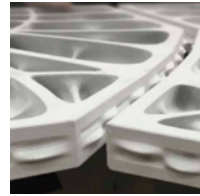


Figure 33 – Concrete floor system that does not require steel reinforcement is 70% lighter than conventional concrete floor. Individual slabs can also be joined together without mortar. Developed at ETH Zurich

M Choose material load bearing structure

Nowadays, concrete is the most common material for the load bearing structure. This is due to the characteristics of concrete: cheap and strong. Unfortunately, the cement with which concrete is made, has a large negative influence on the environment. Other materials are also very suitable for the load bearing structure and are more sustainable. Moreover, hybrid structures (concrete with another material) could also be an option. In the text below, multiple examples for the replacement of concrete are given:

1. Wood
2. Innovative materials
3. Recycled materials
4. Sustainable concrete

1. Wooden structure

Wooden structures are recently gaining attention. However, only a small percentage of the buildings are currently made with a wooden structure (circa 2%). For wooden load-bearing structures, cross-laminated timber (CLT) is often used.

- + Renewable material with less environmental impact
- + Sustainable look of the building
- + Wood has relatively high strength in relation to its weight
- + Wood is a fire safe material
- + Less construction time
- + Less energy costs
- 10-20 % more material costs
- Currently a maximum of 18 floors
- There is not enough space for all the trees necessary to plant in order to replace all concrete structures
- In many cases concrete is still necessary for the foundation of high rise buildings and underground parking (hybrid building)

(Architect 5, 2020, Architect 7, 2020; Client / contractor 3, 2020; Patch22, Mjøstårnet wooden office; Buck et al., 2015).



Figure 34 – Mjøstårnet (Norway) with 85,4 meter the world's tallest timber tower in 2019. Designed by Voll Arkitekter.

- + Facade, insulation, floors, load bearing and interior walls made of same material, no mixing of materials
- + The material is lighter than regular concrete
- + No window frames needed
- + Warmbeton can be transformed to its original resources with a smart crusher
- + Warmbeton is only one of the new promising materials, this market is developing fast
- Depending on the Rc value, the wall needs to be very thick
- Still experimental material, currently it has a maximum height of 4 floors

(Architect 3, 2020; Architect 7, 2020; Architect 6, 2020; Contractor 1, 2020; Architecture Now, 2020; Architecten Cie, 2020; de Leeuw, 2020; Movares, 2020)

2. Innovative material structure

An example of an innovative material is Warmbeton. Warmbeton is a replacement for façade, insulation, floors, load bearing and interior walls. It is thermally insulating ultra-light concrete. The main difference with regular concrete is that all sand and gravel is replaced with glass.

- + Facade, insulation, floors, load bearing and interior walls made of same material, no mixing of materials
- + The material is lighter than regular concrete
- + No window frames needed
- + Warmbeton can be transformed to its original resources with a smart crusher
- + Warmbeton is only one of the new promising materials, this market is developing fast
- Depending on the Rc value, the wall needs to be very thick
- Still experimental material, currently it has a maximum height of 4 floors

(Specialist 3, 2020; Natuurmonumenten Zierikzee; Tilanus, 2017; 2018; Vissering, 2019)



Figure 35 – Office Natuurmonumenten Zierikzee made of the thermal insulating warmbeton. Designed by Architectenbureau Rink Tilanus

3. Recycled materials in the structure

It is possible to use recycled materials in the load bearing structure. Whole elements of a donor building or products can be used (walls, windows, installations, etc.). Also materials which are previously not used in buildings could be a suitable material for the structure. Other options are

the use of materials with high percentage of recycled products (recycled concrete, insulation, carpet, etc.). The search for materials should start early. This is due to the fact that, if recycled materials are used, the design may need to adapt to that.

4. Sustainable concrete structure

Concrete is a relatively cheap, simple, strong and robust material. Therefore, it's widely used in construction. The concrete sector has a large impact on the environment. Currently, this industry is working on becoming more environmentally friendly. Examples of methods to make concrete more sustainable are:

- Earth friendly concrete (EFC). EFC is made with a different binder than Portland cement (most CO₂ comes from this binder). This can be replaced with blast furnace slag (waste product from steel production) and fly ash (waste product from coal power generation)
- Beliet Calciumsulfoaluminaat Ternesiet (BCT)-cement as replacement of Portland cement. This binder accounts for 30% less CO₂
- Capture CO₂ during production process and use it as residual value product
- Use recycled gravel and sand in concrete. The gravel and sand from old concrete can be easily recycled with a smart crusher. Till 20-30% recycled concrete, this has no effect on the properties of the concrete. 100% recycled concrete is possible, but has influence on its strength
- Use bio-based materials in concrete such as elephant grass. The strength of such concrete is lower. Currently, there is still more research necessary into the properties and use of bio-based concrete
- + Concrete is made of raw materials which are not scarce
- + Concrete is a cheap, simple, strong and robust building material
- + There are concrete options which are more sustainable than regular Portland cement concrete. Moreover, many developments are happening in the concrete sector
- + Currently, already 95% of the concrete is reused. However, downcycled and used in the infrastructure sector
- The concrete sector has a crushing impact on the environment
- There is more research is necessary into bio-based concrete
- Using EFC or BCT-cement, the drying time is longer than for Portland cement concrete

(Specialist 3, 2020)

M Minimize earthmoving site

Uncontaminated soil could be recycled among construction sites by optimizing schedule and costs for earthmoving.

- + Reduces costs earthmoving
- + Reduces environmental pressure sector
- Logistics could be challenging

(Client / contractor 6, 2020; Sustainability advisor 1, 2020)



Figure 36 – Excavator during earthmoving on construction site

5.7 Interventions preliminary design

M Reduce material use

When designing a circular office, questions about the possible reduction of materials should always arise. Question whether you need an escalator, an extra elevator, abundant material uses on the in- and outside of the building?

- + Reduction of used materials
- + Reduction of costs
- Balance between necessary elements and needed material use needs to be considered

(Client 1, 2020; Client / contractor 3, 2020; Sustainability advisor, 1, 2020)



Figure 37 – Is it necessary to create workplaces inside a plastic pirate boat surrounded by water?

A Oversizing load bearing structure

If the office should be able to become bigger or smaller (addition of another storey, different lay-out, etc.). This have to be in accordance with the existing load-bearing structure. Extension adaptability and internal adaptability requires that this is accounted for in the early stages of the design process. The load bearing elements (the foundation in particular) have to be strong enough for additional loads. The column grid should also be designed in such a way that it can accommodate different spatial concepts.

- + More functions possible, building is adaptable to changing needs
- + Extra costs for oversizing load bearing structure is smaller than reinforcing the load bearing structure and the foundation later.
- More expensive
- More material needed
- Chance that load bearing elements are unnecessary oversized

(Architect 1, 2020; Architect 6, 2020; Architect 7, 2020; Sustainability advisor 1, 2020; Durmisevic et al., 2019)

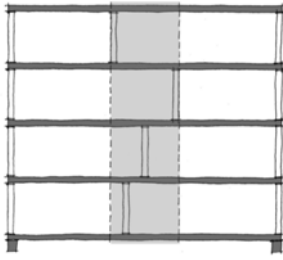


Figure 38 – Flexible and oversized load bearing structure with a section providing movable columns within a predefined area

A Large grid size and high ceilings

A larger grid size provides opportunities to function change of rooms or the complete building. Increasing ceiling height also increases opportunities. According to Dutch law, a ceiling has to be 2,60 meters. Higher ceilings contribute to a pleasant living environment, increase the flexibility of the building and the create opportunity for function change of the building.

- + Suitable for increased number of functions
- + Higher ceilings are perceived as more pleasant
- More expensive
- More material needed
- Chance that load bearing elements are unnecessary oversized

(Architect 1, 2020; Architect 2, 2020; Architect 6, 2020; Architect 7, 2020; Durmisevic et al., 2019)

A Design softspots

Design ‘spots’ in the structure where an opening can be made without influencing the load bearing function. By doing so, floors and/or rooms can be later connected.

- + Increased adaptability office, possible extended functional lifetime
- + Possibility to connect floors/rooms on more places
- Possibility of unused softspots

(Architect 1, 2020)

R Design for Disassembly façade

How facades should look is heavily influenced by the current fashion. Therefore, it can have a significant added value to be able to disassemble the façade. The disassembled façade can be used as a façade at another building or be reused in another purpose. Currently, there are companies which offer façade as a service contract.

- + Extended functional lifespan because of esthetical values, changing the façade of a building can give it a completely new look
- + Extra points BREEAM, MAT8
- Organising the actual reuse of the components of the façade can be difficult

(Architect 3, 2020; Amsterdam International Community School, Durmisevic et al., 2019)



Figure 39 – Drawing of a facade which is designed for disassembly

M Lightweight façade

The skin of an office can be designed with less materials if certain materials are used. For instance, membrane structures of ETFE films. There are more options to design a lightweight façade like bamboo, wood, thin 3D printed concrete, lightweight glass, and more innovative materials.

- + Less material. Make the trade-off between the impact and the weight of the material
- Depending on the type of material used

(Sustainability advisor 1, 2020; Sustainability advisor 2, 2020; Canary Wharf Crossrail Station)



Figure 40 – Canary Wharf Crossrail Station, London. Facade from light, air-filled ETFE foil. Designed by Foster + Partners planned to be finished in 2021

M Choose material for the skin of the building

The skin of the building determines the ‘look’ of the office building. There are many materials possible for the building façade. Moreover, new innovative materials are ever developing. Below three options are discussed:

1. No material: concrete finish
2. Bio-based
3. Recycled material

1. Concrete finish

No finishing of the floor and walls, but use monolithic concrete as finishing. So, there are no façade and plaster walls necessary.

- + No interior and exterior walls required, so less material needed
- + Cheaper
- + Mono-material which increases recyclability
- Construction has to be done more securely.
- Experienced contractor is required

(Specialist 3, 2020; Innovation centre University of Santiago; Mairs, 2014; Nyawara, 2017)



Figure 41 – Innovation centre University of Santiago. 14-storey building made of reinforced concrete with monolithic concrete finish

2. Bio-based façade

There are many options to build a bio-based façade. Some materials give the natural look, such as wood, bamboo and green facades with plants. Other materials are more traditional looking such as loam and lime. It is important that the natural material will not be treated with toxins, this will decrease its reusability.

- + Renewable material
- + Less environmental impact
- Wood is relatively expensive, but loam and lime are cheap raw materials

(Architect 5, 2020, Architect 6, 2020; Patch22, Mjøstårnet wooden office; Buck et al., 2015)



Figure 42 – Country house Zoutelande. This traditionally looking building, is not traditional. It is self-sufficient and made of bio-based materials such as wood, straw, loam, and lime. Designed by ORIO architecten

3. Façade of reused or recycled materials

A façade can be made from 'waste' products or recycled materials. There are many options with different looks, properties and prices

- + Less environmental impact
- + Many possibilities esthetical and practical design options
- Wood is relatively expensive, but loam and lime are cheap raw materials

(Architect 7, 2020; Office MY DVA group; Bicycle storage Eindhoven train station; Architecture Now, 2020; Kwok, 2017)

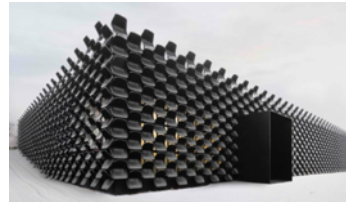


Figure 43 – Office MY DVA group Brno-Vinohrady, Czech Republic. This was a cheap and fast renovation project of an out-dated car showroom where the new facade

M Reduce scarce materials in installations

Some installations are made of several scarce and finite materials. A balance should be made between the amount of installations (heating & cooling) and the amount non-scarce materials used for insulation.

- + Impact on the environment of metals and other finite materials in installations is larger than the impact of the (recycled) materials in insulation. A trade-off should be made
- + Installations are relatively costly, reduction in the amount could decrease costs
- + Lower energy bills due to lower heating and cooling demand
- Space loss due to thick insulated walls

(Specialist 7, 2020; Architect 7, 2020; TVVL, 2020)

A Multifunctional room dimensions space plan

Think about the exact dimensions of your rooms. A room of 7,5x7,5x3 is a flexible module. For our current standard, we can use it for an office, school, two hotel rooms and apartments. Currently, the possible concrete spans determine often the dimensions of rooms, this does not have to be the right dimensions

- + Less alterations when the function of the building changes
- What is perceived as a multifunctional room dimension is influenced by trends

(Architect 1, 2020 Architect 5, 2020; Architect 6; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020; Crowther, 2005; Durmisevic et al., 2019)

A Multifunctional room dimensions space plan

Think about the exact dimensions of your rooms. A room of 7,5x7,5x3 is a flexible module. For our current standard, we can use it for an office, school, two hotel rooms and apartments. Currently, the possible concrete spans determine often the dimensions of rooms, this does not have to be the right dimensions

- + Less alterations when the function of the building changes
- What is perceived as a multifunctional room dimension is influenced by trends

R Standardization of dimensions space plan

Standardized building components are easier reused. This is according to the principle of modular buildings. Standardization in buildings have become a synonym for modularity. Modularity can lead to circularity. In other words, standardized elements can be applied on different places without major renovations. Standardization goes hand in hand with prefab construction

- + Reuse of building components is easier
- + Due to standardization, construction time can be reduced
- + Costs can be reduced by optimisation of building process and standardized units
- Restricted flexibility, flexibility within the borders of the standard dimensions

(Architect 1, 2020; Architect 3, 2020; Architect 5, 2020; Client 1, 2020; Sustainability advisor 3, 2020; Crowther, 2005)

M Produce raw materials on site

Explore the possibilities of producing raw materials on site. For instance, a vegetable garden or algae production.

- + Less environmental impact
- + Possible, positive external effects on the well-being of the users of the office
- The raw material production is not necessarily profitable in terms of money

(Architect 1, 2020; Client / contractor 8, 2020; Potjer, 2018)



Figure 44 – Office garden: fruits, vegetables and happier employees

5.8 Interventions final design

R Use dry joints

In order to disassemble the building or parts of it, dry joints are advised. Bolted in favour of welded connection. Screws in favour of glue and nails.

- + Building can be disassembled without demolishing part of the elements
- + Bolted joints are simpler and cheaper to construct
- Bolted joints have a lower structural performance than welded joints

(Architect 5, 2020; Architect 7, 2020; Client / contractor 2, 2020; Client / contractor 3, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020; Amsterdam International Community School; Bicycle storage Eindhoven train station; CIRCL; City Hall Venlo; Headquarters Alliander Duiven; Hive – Global Foods Innovation Centre Unilever Wagening; Mjöstårnet wooden office; Office Triodos bank Zeist; Patch22; Temporary Courthouse Amsterdam; The Green House Utrecht).



Figure 45 – Bolted steel in load bearing structure (top) & dry joints in wooden load bearing structure in (down, Triodos III, Zeist)

M Choose material types: certified, low impact materials

What kind of concrete, wood, gypsum, aluminium etc. Use LCA to calculate the shadow costs of certain materials and choose the ones with the lowest shadow costs. If materials have certificates of origin according to the ISO1410001, extra point is given for the BREEAM certificate (MAT5). This is an insurance that the materials come from the place that is said

- + Lower shadow costs due to conscience choice of materials
- + Extra point BREEAM qualification
- Possibly higher costs due to the higher price of the more sustainable materials
- Harder to find suitable suppliers

(Specialist 4, 2020; Architect 1, 2020; Architect 2, 2020; Architect 5, 2020; Architect 7, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020; Bicycle storage Eindhoven train station; CIRCL; City Hall Venlo;

Headquarters Alliander Duiven; Hive – Global Foods Innovation Centre Unilever Wagening; Mjöstårnet wooden office; Office Triodos bank Zeist; Patch22; Temporary Courthouse Amsterdam; The Green House Utrecht).

A **R** Easily accessible installations

This is a must. The lifespan of a building depends on the possibility to adapt to new installation technology. The lifespan of installations is relatively short (7-15 years) and it is a fast-developing sector. Moreover, accessibility makes maintenance easier and cheaper. Therefore, installations should be easily accessible. This can be done with:

1. Open ceiling (visible installations)
2. Hidden and accessible installations (suspended ceiling)

1. Open ceiling

A suspended ceiling is often used to hide the installations. Visible installations give an industrial look to your building. An advantage of visible installations is that they're easily accessible for maintenance and replacement. This prolongs the lifespan of the installations but also of the building itself because it can adapt to new installation technologies.

Another theme is about space for your installation closets (air handling units for instance) in order that the maintenance can be carried out and an upgrade is possible, this can be open or in a closed compartment.

- + Easy maintenance of installation
- + Easier to replace installation
- + Saves more money than it costs
- Suspended ceilings are sound absorbing. To create acoustically sound office, extra sound absorbing materials should be used in furniture or the ceiling
- The installer has to work more secure, which costs more time, thus money

(Specialist 7, 2020; sustainability advisor 3, 2020; Architect 3, 2020; Architect 5, 2020; TVVL, 2020)



Figure 46 – Architecture faculty, Delft University of Technology. All the installations are visible and easily accessible

2. Hidden & accessible installations

When the industrial look of an open ceiling is not desirable. The installations can be hidden. Examples of flexible and easily accessible 'hiders' are: flexible skirting boards, or a circular wall system which is made of circular

materials and which is designed for disassembly and easy access to the installations.

- + Less construction time compared to open ceiling
- + Installations are easily accessible and therefore the maintenance is easier
- More materials needed than with an open ceiling
- The maintenance of the installations is still more difficult than with an open ceiling
- It is harder to replace the installations than with an open ceiling
- It is more expensive than an open ceiling

(Specialist 7, 2020; sustainability advisor 3, 2020; Architect 3, 2020; Architect 5, 2020; TVVL, 2020)

R Design for Disassembly installations

The elements in installations have different lifespans and different installations have different lifespans. It is difficult to reuse complete installations, but by designing DfD installations parts could be reused

- + Reuse of materials and components of installations, less environmental impact
- Difficult to accomplish, installations consist of a very large amount of different materials and components

(Specialist 7, 2020; TVVL, 2020)

M Reused installations

CE in the installation market is still in its infancy. Their focus has been on energy. It is a fast developing market, which has to comply with increasingly tightening rules and regulations. Installers are not inclined to take responsibility to reuse installations were they do not know the performance exactly. This makes it difficult to reuse installations

- + Recycling of materials, less environmental impact
- Old installations do not comply with the current regulations or current performance wishes
- Old air ducts are reusable but are extremely dirty, should be cleaned, otherwise health issues
- Nowadays it is almost impossible to get insurance on old installations (installer does not want to take responsibility)
- Dismantling takes more time than demolition

(Specialist 7, 2020; Client / contractor 3, 2020; TVVL, 2020)

A Movable and Design for Disassembly interior walls **R**

If interior walls are easily movable, that increases the adaptability of the space plan of the office. This could extend the lifespan. For instance, a ceiling without bulkheads makes it harder to move the partition walls (ceiling has to be partly removed). Also use materials which are easy to reuse or make panels in standard dimensions, so that they are easy to reuse in a different office.

- + Increased flexibility in layout of the office
- + Interior walls can be used in a different office if necessary
- Increased costs

(Architect 1, 2020; Architect 2, 2020; Architect 5, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020)

5.9 Interventions technical design

R Reduce toxic materials

M

Materials which are free of toxics are more easily reused in different functions. For example, use sustainable paint which is free of toxins. Then the wood from the window pane can have different purposes when it needs to be replaced.

- + Reusability materials increased
- + No materials necessary to produce the toxic materials
- Sometimes paint/lacquer is necessary in order to prolong the lifespan, but often also not

(Architect 7, 2020; Client / contractor 3, 2020; Sustainability advisor 1, 2020; Crowther, 2005)

5.10 Interventions construction documents

R No liquid bonding

Try avoid liquid bonding methods. Using purre, kit, or other regularly used bonding methods in the construction industry, decreases the reusability of the building. It is important to communicate this with the contractor.

- + Dry joints increase reusability building parts because they're disassembled easier
- Building with dry joints costs more time, thus money (it's no common practice yet)

(Architect 5, 2020; Client / contractor 2, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3; Crowther, 2005)



Figure 47 – Adhesives and sealants and other liquid bonding methods are regularly used in construction. But how can this floor be reused when it cannot come off undamaged?

M Reduce construction waste

When designing the office, the amount of waste produced during construction should be minimized. Topics related to this are: work with the standard dimensions of the supplier, minimize transport, prefabrication usually produces less waste.

- + Less waste
- + Less costs
- Has to be managed, site management plan has to be made and followed before and during construction

Sustainable advisor 3, 2020; Contractor 1, 2020; European Environment Agency, 2020)



Figure 48 – Construction waste. During construction, large amounts of waste materials is produced. Construction waste includes waste generated during construction activities and materials that are surplus to requirements (over-ordering, inaccurate estimating)



Circular interior design

The interior exists of partition walls, suspended ceilings, carpeting, furniture, and built-in furniture. There many options to increase the circularity of the interior design. In order to make your interior design circular, the following characteristics should be considered:

1. Flexible & movable
2. Reusable / recyclable
3. Made with sustainable and reused products

1. Flexible & movable interior design

The interior of an office is often changed. Therefore, it is important that interior design is flexible and easily moved to different rooms or even locations.

- + Adaptable interior design can easily change for changing needs, which probably leads to lifespan extension
- Can be more expensive, but TCO is probably cheaper

(Architect 1, 2020 ; Architect 4, 2020; Architect 6, 2020; Client / contractor 2; HAKA building)

2. Reusable / recyclable interior design

In order to reuse or recycle the interior design, interior should be easily disassembled (DfD). Moreover, mono-materials are easier to recycle.

- + Less waste
- + Higher residual value than non-reusable/non-recyclable interior design
- + Easier to change interior
- Can be more expensive, depends on the product

(Architect 1, 2020; Architect 4, 2020; Client / contractor 2; HAKA building; Gispén, 2020)

3. Interior design with sustainable and reused products

Interior design can be made of sustainable materials (renewable, reused, recycled or with low environmental impact). A wide range of sustainable materials and products for interior design is available. Depending on the project and the desired lifespan of this interior, different materials could be chosen.

- + (Partly) reusing own furniture is cheaper
- + Buy-back schemes are also not uncommon (many office furniture suppliers have circular collections)
- + Large supply of carpeting made of reused products
- + Less environmental impact
- Reusing built in furniture from other offices is currently more expensive because suppliers are not specialized in it / more labour costs
- Creating new interior design (partition walls, carpeting, furniture) from second hand material has more labour costs

(Architect 1, 2020; Architect 4, 2020; Client / contractor 2; HAKA building; Hive Collingwood; Gispén, 2020)



Figure 49 – Interior of Hive Melbourne, Australia. The interior design is a mixture of bio-based and reused materials. Designed by Concept Commercial Interiors



Figure 50 – Built in kitchen from greenhouse waste, HAKA building, Rotterdam. Designed by DoepelStrijkers.

Summary chapter 5

Chapter 5 presents the results of this research. It answers the third sub-question:

Within each stage of a design process, what could be circular interventions in the development of an office building?

The answer to this question is shown in the decision support tool (figure 51). The full-coloured boxes indicate which circular interventions can be taken in what stage of the design process of an office building. The decision support tool consists of a frame that combines the building layers, the four circular themes and the stages in a design process (figure 26). This study also provides an filled in version to inspire its users with examples of circular interventions (figure 27, page 52).

When starting a circular project in the initiation phase, the first question that should be asked is, 'Can we built less office space?'. Then the process should be organized. In regards to the circular design itself, the circular focus should be chosen: adaptability, reusability, materials, or a combination of the above. What your project suits depends on the context site, the demand and other external factors (Architect 1, 2020; Architect 5, 2020; Architect 7, 2020; Client / contractor 1, 2020; Specialist 9, 2020; Sustainability advisor 1, 2020; Sustainability advisor 3, 2020).

Because the impact of the interventions on the circularity of the office building decreases, as the design process progresses (Eberthardt et al., 2019; Wamelink, 2010; van Doorn, 2004), the schematic design is an important stage. In this stage, the focus should be on the layers structure and skin. The structure is the most impactful layer of all layers. For the structure the decisions should be made whether it will be a modular and/or design for deconstruction building or that it will implement an open building concept with a robust structure and flexible infill. The materials of the load bearing structure should also be determined. Because the options for the skin depend on the structure and the skin merely determines the outside look of the building, this layer should also be considered in the schematic design (Architect 1, 2020; Architect 2, 2020; Architect 5; 2020, Architect 6; 2020; Sustainability advisor 1, 2020; Sustainability advisor 3; Contractor 1, 2020; Durmisevic et al., 2019; Brand, 1994; Graham, 2005).

In the preliminary design, multiple interventions can be made in different layers of the office building. There are options to increase the adaptability and reusability; overdimensioning the structure and the use of standardised DfD building components in the space plan. In regard to the skin, it is advised to make the façade designed for disassembly because its suitability is heavily influenced by trends and technical innovations (Durmisevic et al., 2019; Client 1, 2020). The amount of services depends on the energy efficiency of the skin, which also depends on the constraints of the structure. As a result, there could be a trade-off made between the amount of scarce materials in the services and the non-scarce materials (Client / contractor 3, 2020, Specialist 4, 2020; Specialist 7, 2020).

In the final design, there is a focus on the services and the space plan. Regarding the detailing of the complete building, connections should be able to disconnect without damaging the building parts. Also, the specific material types should be selected in this stage. Hereby, materials with low environmental impact are preferred (Client / contractor 3, 2020; Contractor 1, 2020; Specialist 4, 2020).

In the technical design, there are not much impactful circular interventions which could be taken. Plans for the interior design could already be made. However, decisions about the interior design are often made during the construction documents or even during the construction phase. The interior design (stuff) could be seen as separate from the rest of the building, due to its relatively short lifespan. Nevertheless, there are currently many option for circular interior design (Architect 1, 2020; Architect 4, 2020; Client / contractor 2, 2020).

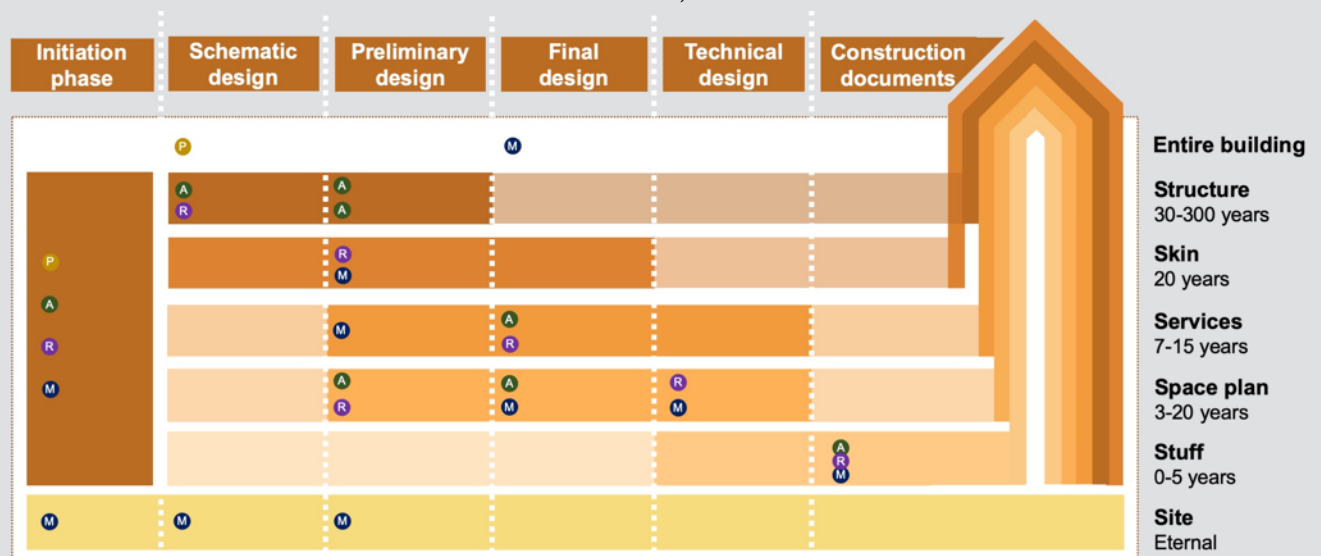


Figure 51 – 'Windows for Circularity', the decision support tool. Version including circular interventions shown on page 52

6 Discussion

6.1 Introduction

This chapter points out the implication of this research for academia and practitioners. The scientific implication mainly focuses on the added value for the body of knowledge and describes the position of this research compared to other studies. The practical implication put this research in its real-life context.

6.2 Research implications for practitioners

The aim of this research is to develop a decision support tool which could improve the communication between the client, architect and contractor about CE and could help designers to make deliberate and impactful circular design choices in the office sector. That is the practical implication of this research. In short, this research will help project managers, and the involved parties to give circularity priority in office building projects.

The decision support tool can be used by designers and clients in different stages of the design process for different purposes. For the client it can serve as an exploratory guide to circular design strategies and learn from different examples. It helps them to better understand what circularity entails in the office building sector. For architects it can also be an exploratory guide and discussion tool to help the conversation about circularity with the client. Moreover, it helps identify specific design-choices based on their characteristics and most suitable design stage.

The following paragraphs focus on the opportunities and problems which can be encountered when developing a circular office. The practical problems are all related to the fact that we are currently living in a linear world. In order to achieve a circular built environment, obstacles still have to be overcome.

Capitalism

We not only live in a linear world, the western world has also a dominating capitalistic worldview. The stakeholders in the office building sector, will not easily let go of their stakes. There are multiple examples in which stakeholders are not eager to change. Such as the installation company, which earns his money from maintenance, would not be eager to minimize the required maintenance for installations. Or the real estate investor for whom the return on investments may decrease when his building has a leased façade. Or the owner of an office building where the elevator is leased but cannot be detached from the building without demolishing it. In this case, the owner has just an expensive maintenance contract for the elevator. Another situation in which interests are intertwined is when a building is Designed for Disassembly. This building would only have recycle potential; it is not certain if the elements will be reused when the time comes that the building will be disassembled. In order to increase the chance of recycling,

material passports could come into play which provide information about the building elements and materials. However, the one who pays for the material passport, does not necessarily benefit from it. Another complication related to capitalism is the lobby of the concrete industry that keeps their position in the market strong. All these problems boil down to the fact that stakeholders are not eager to ruin their current business models. This leaves us with the following questions, 'Who is going to pay for circularity?' and 'Could circularity itself be a business case?'.

The circular economy preaches a different worldview. A worldview in which value is not only measured in short time, monetary profit. Profit however, can have multiple forms or can be indirectly linked to the building. For example, less absenteeism due to a healthier office environment. In the City Hall of Venlo they have secured the financing with such a financial construction. Another example is, making new products from reused parts require more manhour than ordering new products made from raw materials. This extra work could be done by people with intellectual disabilities or unemployment allowances. These people are then happier and need less financial support from the government. Anyway, preserving our earth and its wealth for now, and for all generations to come, should be enough reason to invest in a sustainable built environment. In short, profit does not only come from that certain project budget, cost reduction could come from different budgets or is expressed in another terms than money.

Legislation

When the money issue is sorted out, there is still a legal issue. The Dutch legislation poses some serious limitations to the circular built environment. An example is the current waste management law that complicates the reuse of materials. Moreover, lease agreements for (a part of) buildings to stimulate CE are currently not specified in regulations. Additionally, local land-use plans could also pose threats to the development of circular buildings. To address these problems, new legal frameworks and constructions must be devised (Specialist 8, 2020; Backes & Boeven, 2018).

On the other hand, there are also chances in laws and regulations. It can have a guiding effect on the market. New office buildings in the Netherlands could be more sustainable if stricter rules apply to them. Examples are; an higher required material performance (MPG score), or a mandatory percent of reused materials in buildings, or making material passports compulsory. When we are able to establish a uniform measuring method, it becomes easier to impose stricter rules. Moreover, the circular construction economy can be stimulated by extra tax on materials and a tax discount on labour (Specialist 8, 2020; Backes & Boeven, 2018).

Perspective on circular design

The layman's view on circular design is currently focused on materials. The most famous creeds of the circular economy are; reduce the amount of materials, reuse existing materials as much as possible, and recycle 'waste'. Moreover, the circularity part of the BREEAM certification is also mostly focused on sustainable material use. Notwithstanding that material use is an important aspect of the circular economy in the construction sector, this is not the whole deal. In this research four themes are indicated: adaptability, reusability, materials, and process. Only one of these themes focuses directly on materials. The aim of the other themes is also material reduction and closing material loops. Even so, the relation is less direct.

Adaptability is framed as an important aspect of circular design in this research. Adaptable buildings do not always comply with all the principles of circular design. An adaptable building could have an oversized structure which is cast in concrete. All the same, those buildings could last longer and house multiple functions provided that the infill is flexible. This could increase the lifespan of that office building substantially. Hence extend the material loop and reduce the amount of materials which would have been used to replace the building. Furthermore, adaptability could attract a different kind of investors. The office building sector deals with a relatively high change rate of ownership or users. Additionally, the way we work and use offices is unpredictable and heavily influenced by trends. Therefore, adaptable office buildings have added value. Therefore, it is desired that the results of this research will encourage the design of adaptable buildings.

Reusability is one of the core principles of circular design. Reusability, also referred to as Design for Disassembly, triggers a new way of thinking promoted by the circular economy. Namely, the thought that there is no waste and that waste should be designed out. Notwithstanding the above, Design for Disassembly is a technical solution, aiming at reducing the negative environmental impacts of buildings. However, whether the components and materials are actually reused or recycled in the intended way is outside the scope of circular design. Therefore, the promised positive impact of these circular interventions related to reusability is not guaranteed. This should be considered while designing a reusable building.

An important but underexposed aspect of reusability is standardization. Standardization improves the recycle potential of elements, because the chance that elements need to be adjusted for reuse decreases. Moreover, standardization creates a chance for prefabricated building. In many cases, prefabricated building is less expensive and creates less construction waste. Still, there is a stigma on prefabricated building. Namely, that it is repetitive and has a lower esthetical value. However, with the current techniques and knowledge, prefabricated buildings have the same esthetical value as buildings which are constructed on site.

Lastly, this study focuses on achieving a circular office. However, circularity is a method to achieve sustainability. Sustainability in its broadest sense, has many more facets. The United Nations (2015) indicated seventeen sustainability goals, varying between 'sustainable cities and communities' and 'no poverty'. Trade-offs should be made. For instance between, the amount of materials used and the energy efficiency. But also about allocating the budget to circularity, social responsibility, energy consumption, biodiversity or just to plain, cheap functionality. Unfortunately, allocating budget to circularity or other sustainability aspects is in some projects still a big challenge.

6.3 Research implications for academia

This section discusses the position of this study in relation to other literature. Moreover, the added value of this research will be discussed

6.3.1 Position Windows for Circularity in regards to current body of knowledge

Because the circular economy in the built environment is a relatively novel concept, the literature about this is not substantial. Three groups of scientists who study CE are discussed in this research. These are the pioneers, the conceptualists, and the analysts. The last paragraph refers to Windows of Opportunity, the concept that served as inspiration for this research.

The pioneers

The pioneers are scientists who published studies about the principles of the circular economy. Even though, in their studies these principles were not yet even referred to as circular principles. The most well-known scientists are; Stahel (1946, Switzerland), Habraken (1928, Netherlands), Brand (1938, America), and McDonough (1951, America) & Braungart (1958, Germany).

Walter Stahel has been influential in advocating service-life extensions of goods and closing material loops. In his award-winning paper 'The Product-Life Factor', Stahel (1982) describes the closed loop economy, now referred to as the circular economy. He argues that material loops should be closed and extending product-life optimizes the total lifespan of goods and consequently reduces waste. He has been researching this topic ever since. The work of Stahel (1982; 1994; 2010) provided argumentation to give lifespan extension and adaptability the well-deserved attention in this research.

John Habraken (1961) published the theoretical work 'The carriers and the people; the end of mass housing?'. In his work he proposes Open Buildings, buildings with a sustainable load-bearing structure combined with a flexible infill. The shape of the infill can be determined by the user (Habraken, 1961). After a slow start, his theory has had a lot of influence in the Netherlands, America and Japan. Moreover, Open

Building principles have proven to be valuable tools in the transition towards a circular building industry. Therefore, Open Building principles provided input for the theme adaptability in this research, and has been named in the list of circular interventions.

Steward Brand was a LSD-using, writer and biologist who became famous for his radical and innovative ideas. He stood at the start of the tech industry when he created the Whole Earth Catalogue, the WELL, the Global Business Network and the Long Now Foundation. He is also the author of 'How Buildings Learn: What Happens After They're Built'. This book is about the evolution of buildings and how buildings adapt to changing requirements over long periods. Brand (1994) elaborates on the notion of the different building layers of buildings introduced by Habraken (1961) and the architect Frank Duffy (1990). Hence, he introduces the 6 building layers with different lifespans (Brand, 1994). These building layers has become influential in circular design and has secured a prominent place in this research.

William McDonough & Michael Braungart published in 2002 the book *Cradle to Cradle: Remaking the Way we Make Things*. In this book the Cradle to Cradle (C2C) philosophy is introduced which advocates the same principles as the circular economy (McDonough & Braungart, 2002).

All in all, the ideas of those pioneers and similar theorists led to how we currently view the circular economy in the built environment. Their work planted the seeds for studies about the circular built environment, such as *Windows for Circularity*.

The conceptualists

The concept of circular economy has been studied since the pioneers started with this line of thought. Those scientists can be named the conceptualists. Well-known, conceptual models are the resource and value strategy based on Stahel (1982; 1994; 2010), the Butterfly Model, and the widely used R-models (Bocken et al., 2016; Lüdeke-Freund et al., 2018; Ellen MacArthur Foundation, 2017; Potting et al., 2018). These models succeed in explaining the concept of the circular economy in one figure and provide direction in how to achieve it. Especially R-models explain the 'how to' of CE. However, none of these models is specific for the building industry. Therefore, sector specific circular strategies and interventions are not incorporated in those tools. For the office building sector, the decision support tool of this study, fills this knowledge gap.

The analysts

The analysts are scientists who evaluate the concept in a detailed and analytical way. This research falls also in this category because it also elaborates on the concept and tries to build onwards on the current body of knowledge. There are multiple important works. Kircher et al. (2017) analysed 114 definitions of the circular economy. The works of Bruel et al. (2018), Nasir et al. (2017) and Reike

et al. (2018) went also into depth into the ambiguity of the concept of the circular economy. Together with works from Platform CB'23 (2019) and the conceptualists, they defined the circular economy in the construction industry for this research.

The potential of CE in the built environment and its drivers and barriers are studied by Adams et al. (2017), Eberhardt et al. (2019), Ghisellini et al. (2018), Hart et al. (2019), Kanters (2020), Kircherr et al. (2018), Lacy & Rutqvist (2016). Moreover, multiple interesting reports are written about CE in the built environment. Those focus on the practical and theoretical applications of CE in the building industry and its added value (One Future Play, 2018; McKinsey & Company, 2016; Potting et al., 2017; Rijkswaterstaat, 2018; Thelen et al., 2018; Carra & Magdani, 2017). Based on this literature, the research gap and theoretical background of this study has been established.

Furthermore, in order to execute this study, knowledge about circular design was necessary. Next to interviews and the study of reference projects, information about circular design in the office building sector is gathered through literature. The following works were used: Graham (2005), Durmisevic et al. (2019), Durmisevic & Brouwer (2002), Habraken (1961), Castro & Pasanen (2019), Addis (2006), Amory (2019), Cao et al. (2018), Crowther (2005), Geldermans (2006), Gorgolewski (2008), Guy & Ciarimboli (2008), Macozoma (2002).

Windows of Opportunity vs. Windows for Circularity

Windows of Opportunity is a conceptual approach to understand dynamic policy processes. First introduced by Kingdon (1984), a *Windows of Opportunity* is a short, often fleeting time period in which a desired action can be taken. This happens when three 'streams' are aligned, the problem stream, the policy stream, and the political stream (Kingdon, 1984). *Windows for Circularity* draws inspiration from this well-known approach. However, this concept is admittedly more rigorous and technically approached. *Windows for Circularity* shows for which circular intervention is a *Window of Opportunity* in a certain stage of the design process of an office building. The concept of *Windows for Circularity* could be expanded. The first step to expand this concept is to make the results applicable to the entire building industry. It would also be interesting to study the infrastructure sector or other sectors, but then probably major chances to the research results need to be made.

6.3.2 Scientific added value of Windows for Circularity

This study differs from the current literature in the following aspects: its focus on the office building sector, the linking of scientific circular theory to practise-oriented non-academic literature, and the decision support tool itself is innovative.

Focus on the office building sector

Within the literature in regards to circular building design, there is no specific attention for the office building sector. However, this is a sector which should not be overlooked. To start with, within a year the demand for office buildings has dropped to about zero. The unexpected COVID-19 outbreak was the cause of this. Currently, the expectations are that the way we use offices will never be the same as before the COVID-19 outbreak. Hence, we wish that we built our office according to circular principles, reusable and adaptable. Then it would be easier to give office buildings a new function or reuse large parts of those buildings in other projects or recycle the materials. Unfortunately, this is not the case. Moreover, the demand for office buildings is not only affected by a large one-time event. The office building sector is also susceptible to changing trends. The way we work changes constantly and differs substantially between companies. This makes an additional case for the design of adaptable and reusable buildings.

The design of a circular office building differs from the design of a circular utility, residential or other building. Demand for office buildings is more volatile than for other buildings. This is due to the fact that the needed office space is susceptible to change as described above. Office buildings are also often seen as investment objects, this attracts large investment companies. These companies invest pension money and are forced to take social responsibility. Their great wealth combined with the social pressures, opens possibilities for investments in sustainable and circular office buildings. Moreover, companies are increasingly interested in sustainable solutions for their offices. As a result, the demand for circular offices is increasing. Therefore, this study focuses on circularity in the office building sector. This is a research area that needs more attention.

Link between scientific literature and practice

This study links scientific circular theory to practice-oriented non-academic literature. Especially in non-scientific research, there are many interventions described which stimulate CE in the building industry. To embed this in the current literature, this research is set up.

This research tries to link practical insights to the theoretical framework of circular design. This is done by linking the interventions to circular themes and mapping them in the design process. Resulting in the decision support tool. The circular themes are based on extensive literature research. The circular themes combine the state-of-the-art literature about the circular built environment into four practice-oriented themes. The circular

interventions gathered from practice, can be linked to these themes.

Innovative tool

The decision support tool is innovative because it links the building layers of Brand (1994) to the stages of a design process (BNA & NL ingenieurs, 2014). This has never been done before. This has created added value because it can function as a guide throughout the design process. It points out in what stage of the design process important decisions should be made in relation to circular design of the different building layers. It provides the reader with the tools to decide what has priority in which stage of the design process of a circular office. Another innovative aspect of the decision support tool is the circular themes. The four identified circular themes (adaptability, reusability, materials and process) simplify the core principles of the circular economy and are easy to use in practice. Circular interventions can be linked to those themes. This makes choosing the right circular interventions for a specific project easier.

Summary chapter 6

Chapter 6 discusses the research implication. It answers the fourth sub-question:

In what way could the developed decision support tool be used and implemented in the office building sector?

The decision support tool can be implemented in the office building sector in such a way that it supports communication about CE and provide insight into the possibilities. The decision support tool can be used by designers and clients in different stages of the design process for different purposes. For the client it can serve as an exploratory guide to circular design strategies and learn from different examples. It helps them to better understand what circularity entails in the office building sector. For designers it can also be an exploratory guide and discussion tool to help the conversation about circularity with the client. An example how the decision support tool can be used is explained in appendix G. In short, this research will help project managers and the involved parties to give priority to circularity in office building projects.

Be that as it may, the practical implementation of the research results is not that easy. Using the tool in the design process of an office building is straightforward and would definitely provide suitable and possible interventions for every project. However, achieving circular success in the development of an office building is still not easy. This is due to practical problems related to the fact that we are currently living in a linear world. In this linear system capitalism, legislation and the perspective on circular design, create barriers for the circular built environment. In order to achieve a circular built environment, obstacles still have to be overcome.

Next to a practical implication, this research has also a scientific implication. Windows for Circularity can be seen as a study which is based on principles about the circular built environment discussed by pioneering scientists. It specifies further on the conceptual models developed in the beginning of the 21st century and incorporates ideas and research findings from state-of-the-art literature about the circular built environment. Windows for Circularity differs from the current literature in the following aspects, its focus on the office building sector, the linking of scientific literature to practise-oriented non-academic literature, and the decision support tool itself is innovative. Two aspects of the decision support are innovative. First, it links the building layers to the stages of a design process. This has never been done before and has created added value because it can function as a guide throughout the design process. Second, four circular themes are indicated that simplify the core principles of the circular economy and are easy to use in practise.

7 Conclusions

7.1 Introduction

In this chapter, the conclusion is given. The main research question is answered, the limitations of this research will be discussed, and recommendations for practitioners and follow up research is given. Answers to the sub-questions are answered in the summaries of the previous chapters.

7.2 Conclusion

This paragraph answers the main research question:

How can insight be created into possible circular interventions in the design process of an office building?

This insight can be created by the structuring of circular interventions. To make this transparent to its potential users, a decision support tool has been developed. The aim of this tool is to facilitate the decision-making process towards a circular office. It is a tool to help understand circular design and to be able to prioritize circular interventions.

When designing a circular office, three aspects of circular design need to be taken into account. First, a building consist of different layers with different lifespans. A building layer should be able to be replaced or refurbished without damaging the other building layers. Second, practical circular interventions can be categorized into four themes which are based on circular theory. Those themes are adaptability, reusability, materials and process. Third, circular interventions related to a building layer with a long lifespan should be introduced in an earlier stage of the design process than building layers with a short lifespan. These three aspects and their effect on circular design are explained in the following paragraphs.

First, there should be acknowledged that the basis of circular design of buildings is based on the notion that buildings are not static but a dynamic system of different layers (Graham, 2005; Habraken, 1961; Duffy, 1990). Brand (1994) proposes a model of six layer with each its own typical lifespan. Each layer offers different opportunities to increase the circularity and the lifespan of the entire building. If a building is able to adapt its different layers separately, it will prolong the complete lifespan of the building. Hence, avoiding demolishing of parts which are still functioning (Castro & Pasanen, 2019; Brand, 1994; Stahel, 1982; Graham, 2005; Habraken, 1961; Duffy, 1990).

Second, in order to organise circular interventions, four different circular themes can be indicated: adaptability, reusability, materials, and process. Adaptability refers to a building design that can easily adapt to change. The aim is lifespan extension and avoiding waste streams (Graham, 2005; Habraken, 1961; Duffy, 1990). Reusability refers to the possibility to reuse (parts of) the building. It relates to Design for Disassembly (Graham, 2005; Guy & Ciarimboli, 2008; Durmisevic et

al., 2019). The theme materials refers to direct reduction of materials and the type of materials used. The aim is to reduce the materials used and use materials with less impact (Thelen et al., 2018; Addis, 2006; Klein, 2020). Process relates to the underlying process that stimulate the development of a circular office. Think about new business models where you share services, or the involvement of stakeholders that can bring added value to the project (Versteeg Conlledo, 2019; Venselaar, 2019; van den Berg, 2019). The themes are complementary rather than mutually exclusive.

Third, the design process can be divided between six stages; initiation phase, schematic design, preliminary design, final design, technical design and construction documents. After mapping a great amount of different circular interventions based on their layer, design stage, and circular theme, the following can be concluded: early on decision-making on circularity is beneficial for its implementation in practice. Particularly for long-lived layers (site, structure), early on decision-making is important. Later in the building process, after the schematic design, implementation of circular interventions in the load bearing structure of an office is difficult. Decisions about the circularity in short-lived layers (skin, services, space plan, stuff), can be made later on in the design process. However, the possibilities of the skin and services depend on the structure. As a result, requirements to those layers should be considered when designing the structure. At the same time, decisions about space plan could be made later in the design process (preliminary design and onwards). Circular interventions in the interior design (stuff), can be made in the last stage of the design process (construction documents) or even during construction. Spreading the implementation of circular interventions throughout the design process, improves the chance of achieving a circular office.

7.3 Research limitations

As any research, this study must also be considered in the light of some limitations. The collected data must ensure validity (internal and external), and reliability. Internal validity is the accurate translation of the collection data into conclusions. The external validity is about the translation of the conclusions from the research into a wider context. External validity is also referred to as generalizability. The reliability of a research refers to the replicability of a research. Reliability, as well as internal and external validity has been considered throughout the research process. However, due to certain research characteristics some limitations in regards the validity and reliability of this research can be indicated. These are related to the limited scope, data collection and occurrence of biases. A summarized overview of the research limitations is shown in figure 52.

7.3.1 Limited scope

The research focuses on the office building sector. Due to this focus, the research cannot be applied in the whole building sector. Even though that would yield added value. In practice, the research could also be used in other building projects. However, theoretically this is not sound. Moreover, it is about the design of new, circular building. Transformations are not the focus of this research. A large part of all the buildings is already there. New offices are thus a relatively small market compared to transformations. Still, this focus is chosen because circular interventions for new office designs are less influenceable for external factors and therefore create better insight into all possibilities, generally speaking.

The research also focuses on building level. Circular interventions related to urban development are not in the scope of this study. However, it is advised to take the environment into account while developing a new circular office. Moreover, interventions between buildings in an urban development plan, could support the transition to a circular built environment. When developing a new office, the surrounding should not be overlooked. This study however, does not pay much attention to these kinds of circular interventions.

Another focus of this research is the focus on technical aspects of circular design and how to achieve them in a design process. The regulatory and soft aspects like contracts, business models, business cases, the role of stakeholders, and other process-based interventions are underexposed.

What also should be acknowledged is that the purpose of this research is to enhance the circularity of an office building. Circularity is only a part of sustainability. There are subjects which are also important for sustainable buildings which are not incorporated in this study, such as biodiversity, closing water and energy cycles, and social inclusiveness. Therefore, interventions which improve sustainability in a broader sense, are not taken into account in the decision support tool.

Nevertheless, they should be thought of in the design process of an office building. Examples of interventions which fall into this category are, helophyte filters to reuse grey water, rainwater collection, heat pumps, solar cells, green roofs, solar chimneys, and social work.

There should also be noted that the listed interventions in the decision support tool are not exhaustive. This is due to the fact that it is a fast-developing field of research. The list of possible circular interventions should be regularly updated.

7.3.2 Data collection

A wide range of interviewees was involved in this research. Hence, multiple perspectives of circular design are incorporated in the results. Only the perspective of the demolition party is not represented in the interviews and is covered based on the perspective of other interviewees and literature. This may have led to the underexposure of the demolition party in the decision support tool.

Another limitation of this research is that the reference projects in this study do not comply to triangulation. All the reference projects are based on literature. But in some cases, interviews were also held. This results in an uneven level playing field between the example projects. The sources of the reference projects are listed in appendix F.

Lastly the size of the research poses some limitations. Due to time and resource constraints, only a limited number of experts could be interviewed and a limited number of reference project and literature could be studied. This limitation is tried to be minimized by strategic sampling of interviewees and reference projects. and triangulation in sources. Moreover, it is a design-based research which is iterative at its core. The iterative process has built-in checks and improvements by other researchers, practitioners, and literature. This improves the reliability and the internal validity of the research (Reeves, 2006). Nevertheless, the limited scope still poses a threat to the reliability and validity of this research.

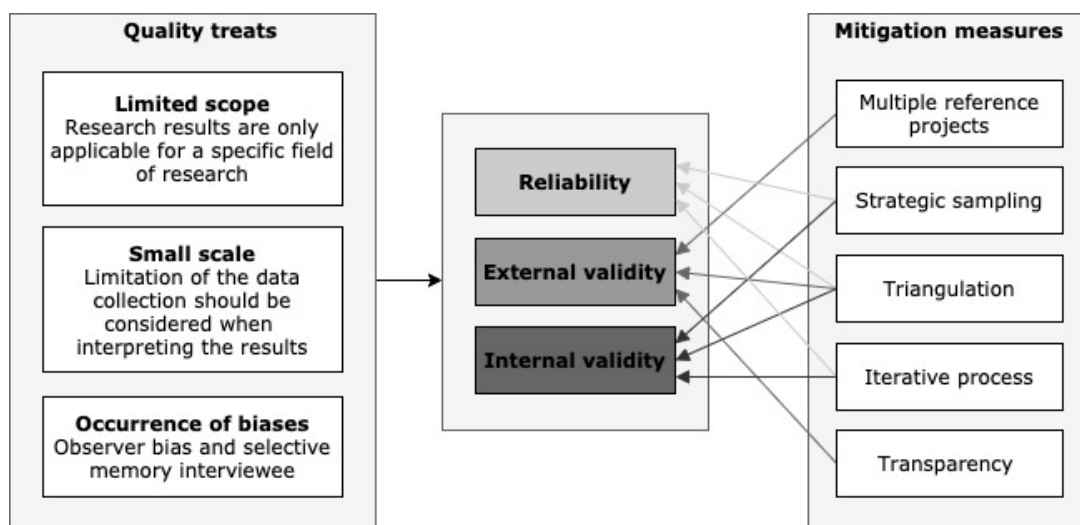


Figure 52 – Overview research limitation (own figure)

7.3.3 Occurrence of biases

Albeit the collection of descriptive knowledge, expert knowledge and project studies focus on interpretation. Therefore, biases may occur. These are related to the researcher and/or the interviewee.

Observer bias can occur. This is based on the researcher's own background and orientation. This limitation is difficult to rule out. To minimize the effect extensive validation through literature, reference projects and feedback sessions have been gathered and triangulation is applied.

Interviewee bias are challenged by several types of bias. Interviewees could have a selective memory, stresses the positive outcomes of their own projects work or knowledge. To minimize this effect, multiple experts from the same perspective are interviewed and their input is checked by literature or reference project where possible.

7.4 Recommendations

Based on the research findings, certain recommendations can be given. Paragraph 7.3.1 suggests follow-up research. Paragraph 7.3.2 provides recommendations for practitioners.

7.3.1 Follow up research

More research into implementing CE in the office building sector is advised. For this sector is now a window of opportunity. This is a small-scale research. Due to time and resources constraints of this research, it is not a large-scale research. Follow-up research is necessary to build onwards the research findings and improve the external validity. Moreover, while executing this research, some new, interesting research topics arose.

First, follow-up research on increasing the external validity of this research findings is advised. This can be done by interviewing more experts, studying more reference projects, and studying case studies in-depth. Moreover, the usability of the decision support tool in real-life should be tested. In this study, the validation of the tool is done by validation interviews and a validation workshop. However, the decision support tool has never been tested in an ongoing project. It is suggested to incorporate that in follow-up research.

Second, expanding the scope of this research can be seen as an interesting research topic. This study brings a prospect generalization into the complete building industry. This could offer more insight into the possibilities of CE in general. This could have important implications not only for the office building sector, but for the complete building sector. Further research is necessary to explore these possibilities.

Third, there are other interesting research topics related to this research. Interesting research topics which arose while executing this research are; research into circular interventions related to a larger scale (urban development), a more in-depth study into the process-

related interventions, expansion of the research about circular possibilities within transformation and renovation projects instead of new building projects, a study into interventions which would affect the use phase of the building and take a broader approach to circularity by including closing energy and water loops.

7.3.2 Recommendations for practitioners

The aim of this research was to improve communication about CE in the office building sector and give inspiration about practical circular interventions. Based on the research findings, recommendations for practitioners about these topics can be formed.

The first recommendation is to get enthusiastic, immerse yourself in circular construction, study the decision support tool in this report and get inspired by the different possibilities of circular design. Subsequently, involve parties who can help you to achieve your ambition to build a circular office and then just start doing. Circular design is a novel practice, so learning by doing is required.

The second recommendation is to convince yourself and others of the added value of a circular office. Depending on the case, a circular office could have added value because of different reasons. For instance, the possibility to adapt your building easily to later uses, or completely disassembly the office building and use it at another location, or low-cost maintenance, or the increased well-being of your employees in a wooden building with lots of green, or the sustainable image of the office building which can be created with the use of reused products. All in the light of decreased sustainability pressures, helping to preserve the earth for future generations.

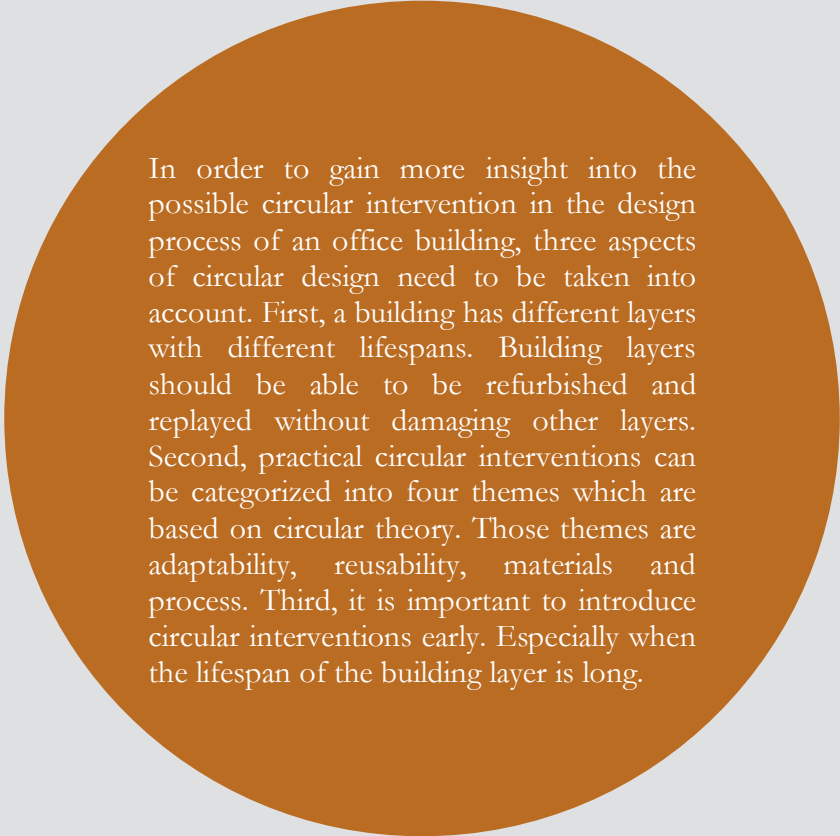
The third recommendation is about circular design. As stated in the conclusion, the basis of circular design is to see a building as a system which consist of building layers with different lifespans. In a circular office, building layers should be separated; a building layer should be able to be refurbished and replaced without damaging other layers.

The fourth recommendation is about the design process and when to implement certain circular interventions. There seem to be a relation between the predicted lifespan of a building layer and when in the design process circular intervention related to this building layer should be introduced. The longer the lifespan, the sooner circular interventions related to this building layer should be introduced. This makes sense, the possibilities for CE in the short-lived layers depend to an extend on the dimensions of the load-bearing structure.

The last recommendation is a reminder that circular construction is a method, and not an aim. The aim is the reduction of environmental pressures, preferably in combination with improved quality and the same or even less costs. Therefore, developing a circular building should never be the highest aim, but a tool to build sustainable and future-proof instead.

Summary chapter 7

Chapter 7 concludes this research. The main research question is answered, the limitations of this research are discussed and recommendations for practitioners and academia are given. The main research question is: '**How can insight be created into possible circular interventions in the design process of an office building?**'. The summarized answer to the research question is:



In order to gain more insight into the possible circular intervention in the design process of an office building, three aspects of circular design need to be taken into account. First, a building has different layers with different lifespans. Building layers should be able to be refurbished and replayed without damaging other layers. Second, practical circular interventions can be categorized into four themes which are based on circular theory. Those themes are adaptability, reusability, materials and process. Third, it is important to introduce circular interventions early. Especially when the lifespan of the building layer is long.

Bibliography

- Abrahamsen, R. (2017). Mjøstårnet - Construction of an 81 m tall timber building. *Internationales Holzbau-Forum IHF 2017*.
- Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers: Waste and Resource Management*, 170(1), 15-24.
- Adams, W. (2015). Conducting semi-structured interviews. In K. Newcomer, H. Hatry, & J. Wholey, *Handbook of practical program evaluation* (4th ed.) (pp. 492-500). Jossey-Bass.
- Addis, B. (2006). *Building with Reclaimed Components and Materials*. London: Earthscan.
- AlbaConcepts. (2019). *Meten is weten! Circulair Paviljoen 'The Green House' Utrecht*. Retrieved from <https://albaconcepts.nl/meten-is-weten-circulair-paviljoen-the-green-house-utrecht/>
- Alliander, Boele & van Eesteren, VolkerWessels Vastgoed, Homij, & RAU (Directors). (2015). *Circulaire Herhuisvesting Alliander* [Motion Picture].
- Allwood, J., Ashby, M., Gutowski, T., & Worrel, E. (2011). Material efficiency. *Resource Conserve Recycle*, 55(3), 362-381.
- Amory, J. (2019). *A Guidance Tool for Circular Building Design*. Delft: Delft University of Technology.
- Arcadis. (2020a). *Fasering*. Arcadis (internal document).
- Arcadis. (2020b, February 25). *Visiedocument Duurzaamheid Divisie Gebouwen*. Retrieved from Internal source (not publicly available)
- Arcadis. (2020c). *Who we are*. Retrieved from <https://www.arcadis.com/en/global/who-we-are/#>
- Archdaily. (2014). *Innovation Center UC - Anacleto Angelini / Alejandro Aravena | ELEMENTAL*. Retrieved from <https://www.archdaily.com/549152/innovation-center-uc-anacleto-angelini-alejandro-aravena-elemental>
- Architecten Cie. (2020). *More space for the bike at Eindhoven station*. Retrieved from <https://cie.nl/page/1338/meer-ruimte-voor-de-fiets-op-station-eindhoven?lang=en>
- Architecture Now (Director). (2020). *De keten van circulaire bouw* [Motion Picture].
- ArchitectuurNL. (2019, February 14). *Architectuur in glasschuimbeton aan Zeeuwse kust*. Retrieved from <https://www.architectuur.nl/project/architectuur-in-glasschuimbeton-aan-zeeuwse-kust/>
- Baarda, D., Bakker, E., Fischer, E., Julsing, M., de Goede, M., Peters, V., & van der Velden, T. (2013). *Basisboek kwalitatief onderzoek* (3rd ed.). Groningen: Noordhof Uitgevers.
- Backes, C., & Boeve, M. (2018). *Enkele juridische vragen rond een circulaire economie in de bouw*. Utrecht: Utrecht Centre for Water, Oceans and Sustainability Law.
- Bakker, C., den Hollander, M., van Hinte, E., & Zijlstra, Y. (2014). *Products that last - product design for circular business models*. TU Delft.
- Bekier, J., & Vedel-Jørgensen, M. (2017). *Circular Economy: Where Sustainability Means Business?* Copenhagen Business School.
- BNA, & NL ingenieurs. (2014). *Standaardtaakbeschrijving - DNR-STB 2014 - Toelichting*. Amsterdam.
- Bocken, N., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Sustainable Design and Manufacturing for Circular Economy*, 33(5), 308-320.
- Braendstrup, C. (2017). *Conceptual design of a demountable, reusable composite flooring system*. Delft: Delft University of Technology.
- Brand, S. (1994). *How Buildings Learn - What Happens After They're Built*. New York: Penguin Books.
- BREEAM. (2019). *Unilever Food Innovation Center, Netherlands*. Retrieved from <https://www.breeam.com/case-studies/mixed-use/unilever-food-innovation-center/>.
- BREEAMNL. (2013, February 22). *Huisvesting Alliander Duiven*. Retrieved from <https://www.breeam.nl/projecten/huisvesting-alliander-duiven>
- Brown, A. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of Learning Sciences*, 2(2), 141-178.
- Bruel, A., Kronenberg, J., Troussier, N., & Guillaume, B. (2018). Linking Industrial Ecology and Ecological Economics: A Theoretical and Empirical Foundation for the Circular Economy. *Journal of Industrial Ecology*, 23(1), 12-21.
- Brundtland, G. (1987). *Our Common Future*. World Commission on Environment and Development (WCED).
- Bruning, R. (2013). *Flexibel wonen in Amsterdam Noord*. Delft: Delft University of Technology.
- Buck, D., Wang, X., Hagman, O., & Gustafsson, A. (2015). Comparison of Different Assembling Techniques Regarding Cost, Durability, and Ecology - A Survey of Multi-layer Wooden Panel Assembly Load-Bearing Construction Elements. *BioResources*, 10(4).
- C2C ExpoLAB. (2014). *Case study: City of Venlo*. Venlo: C2C ExpoLAB.
- Camacho-Otero, J., Boks, C., & Pettersen, I. (2018). Consumption in the Circular Economy: A Literature Review. *Sustainability*, 10(8), 2758.
- Cao, X., Li, X., Yan, Y., & Yuan, X. (2018). Skeleton and Infill Housing Construction Delivery Process Optimization Based on the Design Structure Matrix. *Sustainability*, 10(12).
- Carra, G., & Magdani, N. (2017). *Circular Business Models for the Built Environment*. Arup, BAM, CE100.
- Castro, R., & Pasanen, P. (2019). How to design buildings with Life Cycle Assessment by accounting for the material flows in refurbishment. *Earth Environment Science*, 225-226.
- Cepezed. (2018, April 12). The Green House Utrecht - cepezed. *De Architect*.

- Cepezed. (2020). *Tijdelijke Rechtbank Amsterdam*. Retrieved from <https://www.cepezed.nl/nl/project/tijdelijke-rechtbank-amsterdam/30529/>
- Churchill, W. S. (1950). *The Second World War: Triumph and Tragedy* (Vol. 6). London.
- Churchill, W. S. (1950). *The Second World War: Volume V! Triumph and Tragedy* (Vol. 6). London.
- Churchill, W. S., & Gilbert, M. (1982). *The Coming of War 1936-1939*. London: Heinemann.
- CHYBIK + KRISTOF. (2019). Facade as a functional banner. *ArchDaily*.
- CIRCL. (2020). *The making of CIRCL...* Retrieved from <https://circl.nl/themakingof/en/>
- Cirkelstad. (2020, February 11). *100% modulaire en demontabele school*. Retrieved from Cirkelstad : <https://www.cirkelstad.nl/100-modulaire-en-demontabele-school/>
- Cobouw. (2017, November 3). *Job Dura: 'Dit is in 2019 het meest circulaire en intelligente gebouw van Nederland'* . Retrieved from <https://www.cobouw.nl/utiliteitsbouw/nieuws/2017/11/job-dura-dit-2019-het-meest-circulaire-en-intelligente-gebouw-van-nederland-101254389>
- Collins, A. (1992). Towards a design science of education. In E. Scanlon, & T. O'Shea, *New directions in educational technology* (pp. 15-22). Berlin: Springer.
- Crone, J. (2016, November 18). *Tijdelijke Rechtbank Amsterdam*. Retrieved from Bouwwereld: <https://www.bouwwereld.nl/project/tijdelijke-rechtbank-amsterdam/>
- Crossrail. (2020). *Canary Wharf Station*. Retrieved from <https://www.crossrail.co.uk/route/stations/canary-wharf/#>
- Crowther, P. (2001). Developing an inclusive model for design for deconstruction. In A. Chini, *Deconstruction and Materials Reuse* (pp. 1-25). Wellington: University of Florida.
- Crowther, P. (2005). Design for Disassembly – Themes and Principles. RAI/BDP Environment Design Guide. *Environmental design guide*, 1-7.
- Dalkmann, H., Herrera, R., & Bongardt, D. (2003). Analytical strategic environmental assessment (ANSEA) developing a new approach to SEA. *Environmental Impact Assessment Review*, 24(4), 385-402.
- de Leeuw, M. (2020, February 6). *Oude rails en treinen nieuwste project voor Circl-architect: 'Circulair blijft reuze ingewikkeld'*. Retrieved from De Architect.
- de Meeuw. (2020). *Amsterdam International Community School*. Retrieved from de Meeuw : <https://www.demeeuw.com/projecten/amsterdam-international-community-school>
- Design Council. (2007). *A study of the design process*. London: Design council.
- Design Council. (2019, September 2). *What is the framework for innovation? Design Council's evolved Double Diamond*. Retrieved March 2020, from Design Council: <https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond>
- DGBC. (2020). *DGBC: van circulair beleid naar ontwerpen en bouwen*. Retrieved from Dutch Green Building Council: <https://www.dgbc.nl/agenda/dgbw-van-circulair-beleid-naar-ontwerpen-en-bouwen-81>
- DoepelStrijkers. (2011). *HAKA RECYCLE OFFICE*. Rotterdam: DoepelStrijkers, de URBANISTEN, BVR.
- Durmisevic, E., & Brouwer, J. (2002). Design aspects of decomposable building structures. *Delft University of Technology*.
- Durmisevic, E., Jorissen, A., Nijsen, R., Broek, K., Jacobs, J., Stoutjesdijk, P., & Ribberink, M. (2019). Design Strategies for Reversible Buildings. *Circular Economy in Construction*.
- Duurzaam Gebouwd. (2019, August 30). *Modulair schoolgebouw in Amsterdam dankzij Brexit*. Retrieved from Duurzaam Gebouwd - Het integrale platform: <https://www.duurzaamgebouwd.nl/artikel/20190830-modulair-schoolgebouw-in-amsterdam-dankzij-brexit>
- Eberhardt, L. C., Birgisdottir, H., & Birkveld, M. (2019). Potential of Circular Economy in Sustainable Buildings. *Buildings IOP Conference Series: Materials Science and Engineering*, 471(092051).
- Ellen MacArthur Foundation. (2013). *Towards the Circular Economy: Economy and Business Rationale for Accelerated Transition*. Cowes: Ellen MacArthur Foundation.
- Ellen MacArthur Foundation. (2017). *What is circular economy?* Retrieved from <https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy>
- Ellen MacArthur Foundation. (2019). *Completing the Picture: How the Circular Economy Tackles Climate Change*. Ellen MacArthur Foundation & Material Economics.
- Engelman, R. (2013). Beyond Sustainability. In State of the World 2013. *Island Press / Center for Resource Economics*, 3-16.
- European Commission. (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives*. Retrieved from <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN>
- European Commission. (2019). *The implementation of the Circular Economy Action Plan*. Brussels.
- European Environment Agency . (2016). *Circular Economy in Europe Developing the Knowledge Base*. Copenhagen: European Environment Agency.
- European Environment Agency. (2020). Construction and demolition waste: challenges and opportunities in a circular economy. *Resource efficiency and waste*, January.
- Evers, J. (2019). *Circulaire Architectuur - Aan de hand van Triodos III*. Amsterdam: RAU.

- Fellows, R., & Liu, A. (2015). *Research methods for construction*. John Wiley & Sons.
- Flyvberg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, 12, 219-245.
- FRANTZEN architects. (2017). *High-rise in wood*. Retrieved from Patch22.
- Geldermans, R. (2016). Designing for change and circularity - accommodating circular material & product flows in construction. *Energy Procedia*, 96, 301-311.
- Gemeente Venlo. (2020). *C2C Venlo - City Hall Venlo*. Retrieved from <https://c2cvenlo.nl/en/city-hall-venlo/>
- Gerding, D. (2019). *Talking circularity - the influence of actors on the building process*. Delft: Delft University of Technology.
- Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, 178, 618-643.
- Gorgolewski, M. (2008). Designing with reused building components: some challenges. *Building Research and Information*, 36(2), 175-188.
- Grafton-Green, P. (2019, March 1). *First glimpse inside 'biggest and best' Elizabeth line station at Canary Wharf as it nears completion*. Retrieved from Evening Standard.
- Graham, P. (2005). *Design for adaptability- an introduction to the principles and basic strategies*. Australia: The Royal Australian Institute of Architects.
- Guy, B., & Ciarimboli, N. (2008). *Design for disassembly in the built environment: A guide to a closed-loop design and building*.
- Habraken, J. (2003). *Open Building as a condition for industrial construction*. MIT.
- Habraken, N. (1961). *De dragers en de mensen - het einde van de massawoningbouw*. Amsterdam: Stichting Architecten Research.
- Hannema, K. (2016, October 26). *Woon-werkgebouw* Patch22. Retrieved from ArchitectuurNL.
- Hart, J., Adams, K., Gieseke, J., Tingley, D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: the case of the built environment. *Procedia CIRP*, 80, 619-624.
- Herrington, J., McKenney, S., Reeves, T., & Oliver, R. (2007). Design-based research and doctoral students: Guidelines for preparing a dissertation proposal. (pp. 4089-4097). Chesapeake: World Conference on Educational Multimedia.
- Hinde, D. (2017). *PRINCE2 Study Guide*. New York: John Wiley & Sons Inc.
- Hive. (2020). *Hive Collingwood, Melbourne*. Retrieved from <https://thehivecollingwood.com/#>
- Hoffman, C. (2017, April 10). Modern construction using long-forgotten techniques. *ETH Zürich*.
- Huang, S. L., & Hsu, W. L. (2003). Materials flow analysis and 'exergy' evaluation of Taipei's urban construction. *Landscape and Urban planning*, 62(2), 61-74.
- Kanters, J. (2020). Circular Building Design: An Analysis of Barriers and Drivers for a Circular Building Sector. *Buildings*, 10(4).
- Kickert, W., Klijn, E., & Koppenjan, J. (1997). *Managing complex networks*. London: Sage.
- Kingdon, J. (1984). *Agendas, alternatives, and public policies*. New York: Harper Collins College Publishers.
- Kircherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence from the European Union. *Ecological Economics*, 150, 264-272.
- Kircherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221-232.
- Klein, T. (2020). *Introduction to a Circular Economy for a Sustainable Built Environment*. Retrieved from edX MOOC Delft University of Technology: https://delftxdownloads.tudelft.nl/CESBE1x_Circular_Economy_Built_Environment/Module_1/CESBE1x_2019_1_1_Introduction_to_the_MOOC-slides.pdf
- Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, 175, 544-552.
- Kraaijvanger Architects. (2016). *Stadskantoor Venlo*. Rotterdam: Kraaijvanger Architects.
- Kvale, S. (2008). *Doing interviews*. SAGE Publications Ltd.
- Kwok, N. (2017, April 27). *CHYBIK + KRISTOF installs facade made of chairs for furniture pavilion*. Retrieved from Designboom.
- Lüdeke-Freund, F., Gold, S., & Bocken, N. (2018). A Review and Typology of Circular Economy Business Model Patterns. *Journal of Industrial Ecology*, 1-26.
- Lacy, P., & Rutqvist, J. (2016). *Waste to Wealth: The Circular Economy Advantage*. London: Palgrave.
- Lansink, A. (1979). *De ladder van Lansink*. Retrieved from www.adlansink.nl
- Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner Production*, 176(1), 976-989.
- Levermore, G. (2008). A review of the IPCC Assessment Report Four, part 1: The IPCC process and greenhouse gas emission trends from buildings worldwide. *Building Services Engineering Research*, 29(4), 349-361.
- Lindner, G., & Lendt, B. (2010). NEXT21 - an experiment. *Open and Sustainable Building* (pp. 63-64). Bilbao: Labein Tecnalia.
- Loesje. (2017, December 28). *Circulaire economie, soms werkt het dus wel om in kringetjes te denken*. Retrieved from Loesje: <https://www.loesje.nl/posters/circulaire-economie-soms-werkt-dus-wel-om-kringetjes-denken170928/>

- Lucon, O., Ürge-Vorsatz, D., Zain Ahmed, A., Akbari, H., Bertoldi, L., Cabeza, L., & Eyre, N. (2014). Buildings. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- Macozoma, D. (2002). *Understanding the Concept of Flexibility in Design for Deconstruction Proceedings of the CIB Task Group 39*. CIB Publication.
- Mairs, J. (2014, November 5). *Giant openings puncture Elemental's monolithic concrete innovation centre*. Retrieved from <https://www.dezeen.com/2014/11/05/elemental-innovation-center-uc-anacleto-angelini-university-concrete-santiago-chile/>
- McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point Press.
- McKinsey & Company. (2016). *Why the circular economy is all about retaining value*.
- Merrild, H., Jensen, K., & Sommer, J. (2016). *Building a Circular Future*. Copenhagen: GXN.
- Moelven. (2020). *Mjostårnet*. Retrieved from <https://www.moelven.com/mjostarnet/>
- Morgan, J., & Mitchell, P. (2015). *Employment and the Circular Economy: Job Creation in a More Resource Efficient Britain*. London: Green Alliance and WRAP.
- Morseletto, P. (2020). Targets for a circular economy. *Resources, Conservation and Recycling*, 153.
- Movares. (2020). *Circulaire en duurzame fietsenstalling Eindhoven*. Retrieved from <https://movares.nl/projecten/circulaire-en-duurzame-fietsenstalling-eindhoven/>.
- Muis, R. (2019, September 12). *Nieuwe kantoor Triodos Bank is ook een materialenbank*. Retrieved from Architectenweb.
- Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140(3), 369-380.
- Nasir, M. H., Genovese, A., Acquaye, A., Koh, S. C., & Yamoah, F. (2017). Comparing linear and circular supply chains: A case study from the construction industry. *International Journal of Production Economics*, 183(PB), 443-357.
- Nationale Staalprijs. (2018). *Tijdelijke Rechtbank Amsterdam*. Retrieved from <https://www.nationalestaalprijs.nl/project/tijdelijke-rechtbank-amsterdam>
- NEN-EN 15643-2 . (2011). *Duurzaam bouwen - Beoordeling van gebouwen - Deel 2: Raamwerk voor de beoordeling van milieuprestaties*. NEN.
- Ness, D., Kim, K., Swift, J., Jenkins, A., Xing, K., & Roach, N. (2020). Cradle to Cradle Building Components Via the Cloud: A Case Study. In R. Roggema, & A. Roggema, *Smart and Sustainable Cities and Buildings*. Springer.
- Niessink, R., Menkveld, M., & Sipma, J. (2017). *Verkenning utiliteitsbouw*. ECN.
- Nyawara, B. (2017, August 25). *University of Chile's Innovation Centre: Alejandro Aravena's Subtle Monolith*. Retrieved from <https://www.archute.com/university-chiles-innovation-centre-alejandro-aravenas-subtle-monolith/>
- Ollongren, K. H. (2019, October 8). *Maatregelen voor het bevorderen van de circulaire economie*. Retrieved from <https://www.rijksoverheid.nl/documenten/kamerstukken/2019/10/08/kamerbrief-over-maatregelen-voor-bevorderen-circulair-bouwen>
- One Future Play. (2018). *Samen circulair ontwerpen - Circulaire architectuur en bouw*. Amsterdam: BNA & Rijksdienst voor Ondernemend Nederland.
- Orio Architecten. (2018, July 27). *Buitenplaats Kustlicht in Zoutelande*. Retrieved from <https://orioarchitecten.wordpress.com/2018/07/27/buitenplaats-kustlicht-in-zoutelande/>
- Platform CB'23. (2019). *Kernmethode voor het meten van circulariteit in de bouw*.
- Platform CB'23. (2019). *Lexicon Circulair Bouwen*.
- Potjer, W. (2018, May 2). *Vijf inspirerende voorbeelden van Urban Farming*. Retrieved from <https://www.hetkanwel.nl/2018/05/02/vijf-inspirerende-voorbeelden-urban-farming/>
- Pots, J. (2018). *How procurement processes can realize a transition arena that is required in order to stimulate the transition to a circular economy*. Enschede: University of Twente.
- Potting, J., Hekkert, M., Worrel, E., & Hanemaaijer, A. (2017). *Circular Economy: Measuring Productivity in the Product Chain*. Planbureau voor de Leefomgeving.
- Project Management Institute. (2017). *A guide to the Project Management Body of Knowledge*. Philadelphia: PMI.
- RAU. (2020). *Triodos Bank Nederland*. Retrieved from <https://www.rau.eu/portfolio/triodos-bank-nederland/>
- Raworth, K. (2017). *Doughnut Economics - Seven Ways to Think Like a 21st Century Economist*. Vermont: Chelsea Green Publishing.
- Reeves, T. (2006). Design research from a technology perspective. In *Education Design Research* (pp. 52-66). London: Routledge.
- Reike, D., Vermeulen, W., & Witjes, S. (2018). The circular economy: new or refurbished as CE 3.0? - exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention. *Resource Conserve Recycle*, 135, 246-264.
- Reyna, J., & Chester, M. (2015). The Growth of Urban Building Stock: Unintended Lock-in and Embedded Environmental Effects. *Journal of Industrial Ecology*, 19, 524-537.
- Rijksoverheid. (2016). *Nederland circulair in 2050 - Rijksbreed programma Circulaire Economie*. Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken.

- Rijksoverheid. (2018). *Transitieagenda Circulaire Bouweconomie*.
- Rijkswaterstaat. (2015). *Circular economy in the Dutch construction sector - a perspective for the market and government*.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F., Lambin, E., . . . Hansen, J. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14(2).
- Scharpf, F. (1997). *Games real actor play: actor-centered institutionalism in policy research*. Boulder USA: Westview Press.
- Seto, K. C., Dhakal, S., Bigio, H., Blanco, H., Delgado, G. C., Dewar, D., & Huang, L. (2014). Chapter 12 - Human settlements, infrastructure and spatial planning. In *Climate Change 2014: Mitigation of Climate Change*. Cambridge University Press.
- Spacestor. (2020, March 30). *The Hive Collingwood Coworking Offices, Melbourne*. Retrieved from <https://spacestor.com/insights/cool-workspaces/workspace-of-the-week-the-hive-collingwood-coworking-offices-melbourne/>
- Stahel, W. (1982). The product-life factor. In S. Grinton Orr, *An Inquiry into the Nature of Sustainable Societies: The Role of the Private Sector* (pp. 72-96). Houston: HARC.
- Stahel, W. (1994). The utilization focused service economy: Resource efficiency. In B. Allenby, & D. Richards, *The Greening of Industrial Ecosystems* (pp. 178-190). Washington: National Academy Press.
- Stahel, W. (2010). *The Performance Economy*. Hampshire UK: Palgrave Macmillan Hampshire.
- Stahel, W. (2016, March 23). *The circular economy*. Retrieved April 2020, from Nature: <https://doi.org/10.1038/531435a>
- Svarok. (2017). *Zoutelande*. Retrieved from <http://www.svarok.com/onze-projecten/zoutelande/>
- Teisman, G. (2000). Models for research into decision-making processes: on phases, streams and decision-making rounds. *Blackwell Publishers*.
- Thelen, D., van Acoleyen, M., Huurman, W., Thomaes, T., van Brunschot, C., Edgerton, B., & Kubbinga, B. (2018). *Scaling the circular built environment*. Geneva: WBCSD, Arcadis, Circle Economy.
- Thorns, E. (2018, February 15). *World's Tallest Timber Tower to Be Built in Norway*. Retrieved from ArchDaily.
- Tilanus, N. (2017, April 28). Dit gebouw krijgt een olifanten huid. *De Volkskrant*.
- Tilanus, N. (2018, September 4). ARC18: Levensstrijdweg 1. *De Architect*.
- Tilman, H. (2017). Thomas Rau: 'Om circulair te worden, moet we oefenen in doen wat nodig is'. *De Architect*.
- TVVL (Director). (2020). *Webinar ontwerpstrategie Circulaire Installaties | Demonstratie Circulariteitsschiff* [Motion Picture].
- UKGBC. (2019). *Circular economy guidance for construction clients*. London: UKGBC.
- UNEPFI. (2019). *UN-Convened Net-Zero Asset Owner Alliance*. Retrieved from <https://www.unepfi.org/net-zero-alliance/>
- Unilever. (2020). *Hello, we're Hive - Unilever's Foods Innovation Centre*. Retrieved from <https://www.unilever.com/about/innovation/hive/>
- United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*.
- United Nations Environmental Program. (2012). *Sustainable, resources efficient cities — Making it happen*. Paris: UNEP.
- van den Berg, M. (2019). *Managing Circular Builgin Projects*. Enschede: University of Twente.
- van der Werf, F., & Froyen, H. (1980). Experimental Housing Project. In Molenvliet-Wilgendonk, *Beyond the Modern Movement*. The Harvard Architecture Review.
- van Stigt, R., Driessen, P., & Spit, T. (2013). A window on urban sustainability: Integration of environmental interests in urban planning through 'decision windows'. *Environmental Impact Assessment Review*, 42, 18-24.
- van Woerkom, L. (2016). *Tijdelijke Rechtbank Amsterdam*. Cepezed, Delft.
- Verschuren, P., Doorewaard, H., & Mellion, M. (2010). *Designing a Research Project (second edition)*. The Hague: Eleven International Publishing.
- Versteeg Conlledo, A. (2019). *Managing circular construction projects*. Delft: Delft University of Technology.
- Vissering, C. (2019). Esthetische zoektocht uitvoering warmbeton. *Tektoniek*.
- Vos, R., Heintz, R., & Strating, N. (2018). The Greenhouse: A case study on a circular hospitality building in Utrecht analysing its circularity and integration of the Nexus philosophy in combination with a positive business case. *Future Sustainable Cities, Green operations for hospitality*.
- Wang, K., Vanassche, S., Ribeiro, A., Peters, M., & Oseyran, J. (2017). Business models for building material circularity: learnings from frontrunner cases. *International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste*, 21-23.
- Wieldraayer, J. (2019, October 22). *Van BIM-model naar materialenpaspoort*. Retrieved from The New Builders: <https://www.thenewbuilders.nl/nieuws/van-bim-model-naar-materialenpaspoort-een-blog-door-bim4all/>
- World Resources Institute. (2016). *Accelerating building efficiency: Eight actions for urban leaders*. WRI and WRI Ross Center for Sustainable Cities.
- Young, N. (2020). *Canary wharf crossrail station - 10,000sqm membrane construction*. Retrieved from Seele: <https://seele.com/references/canary-wharf-crossrail-station>
- Yu, H., Al-Hussein, M., Al-Jibouri, S., & Telyas, A. (2013). Lean Transformation in a Modular Building Company: A Case for Implementation. *Journal of Management in Engineering*, 29(1).

Appendices

Appendix A – Glossary

The table below presents the definitions used in the report. The correlating sources are mentioned after the definition description. There is tried to use the most widely recognized definitions in order to make it useful and understandable for so many people as possible.

Definition	Description
Adaptive ability building	Includes all the features that allow a building to retain its functionality in a sustainable and economically viable manner throughout its technical lifecycle, under changing needs and circumstances (Platform CB'23, 2019, p. 4)
Bio based construction	Is a building with bio-based building materials and / or application of bio-based products (Platform CB'23, 2019, p. 5)
Bio based materials	Are materials (or products) that are made from renewable, organic raw materials instead of fossil raw materials (Platform CB'23, 201, p. 59)
Circular construction	Circular construction is the development, use and reuse of buildings, areas and infrastructure, without unnecessarily depleting natural resources, polluting the living environment and affecting ecosystems by using as many renewable raw materials as possible. Building in a way that is economically, socially, culturally and ecologically responsible. Here and there, now and later (Platform CB'23, 2019, p. 6)
Circular design	Circular design as referred to in this research, is the act of designing a circular building. The aim of circular design is to design a plan for a circular structure and with that enhancing the circular economy
Circular economy	The circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation, 2017, p. 1)
Circular intervention	Is an action which is in line with a circular strategy. A circular intervention aims to design out waste and/or pollution and/or keeping products and materials in use and/or regenerating natural systems
Circular strategy	Aims for designing out waste and pollution, keeping products and materials in use, and regenerating natural systems
Circular structure	Is a structure that: as been designed and implemented in accordance with circular design principles and has been realized with circular products, elements and materials (Platform CB'23, 2019, p. 3)
Closed loop system	System in which products, components or materials are reused or recycled by an organization or a co-operating group of organizations into the same or similar products, components or materials with minimal loss of quantity, quality or function (Stahel, 1982; 1994; 2010)
CPG	Circular performance building (Dutch: Circulariteitsprestatie Gebouwen) is a method, developed by WE Adviseurs, that can determine the degree of circularity of a building or plan for new construction or renovation
Cradle-to-Cradle (design philosophy)	Cradle-to-Cradle (C2C) is a design philosophy, in which all waste is food for something new, using clean energy, and using no toxic materials. An important underlying principle is that C2C not only wants to limit the negative footprint, but also wants to achieve a positive footprint (McDonough & Braungart, 2002; Murray et al., 2017)
Cradle-to-Cradle (label)	Cradle-to-Cradle (C2C) is a label system that assesses the extent to which products comply with the design principles of Cradle-to-Cradle (Platform CB'23, 2019, p. 7)
Critical raw material	Are scarce materials, which are essential for certain industries and whose security of supply is low (Platform CB'23, 2019, p. 7)
Degradable	A characteristic of a product or packaging that, with respect to specific conditions, allows it to break down to a specific extent within a given time (Platform CB'23, 2019, p. 7)
Design for Disassembly	Design for Disassembly focuses on designing a composite construction product or element in such a way that it cannot be disassembled destructively. It is preferred that disassembly is as easy as possible (Platform CB'23, 2019)
Design process	In this report the design process refers to the time that a building is designed. The design process consists of 6 stages: initiation phase, schematic design, preliminary design, final design, technical design and construction documents (BNA & NL ingenieurs, 2014)
Downcycle	Process of converting secondary raw materials/by-products into new materials, components or products, typically of lesser quality, reduced functionality and/or lower value compared to their original intended purpose (Platform CB'23, 2019, p. 7)
Economic life	The economic life of a structure is the life over which a structure is depreciated upon realization (Platform CB'23, 2019, p. 7)
Functional life	The functional life of a structure is the life within which the structure remains suitable for its function (Platform CB'23, 2019, p. 8)

High-quality reuse	In case of high-quality reuse, the secondary material has in principle the same quality as the original (new or primary) material (Platform CB'23, 2019, p. 9)
LCA	A Life Cycle Assessment (LCA) is a method for determining and evaluating the incoming and outgoing flows, and potential environmental impacts of a product system during its life cycle.
Lifespan	When in this report is talked about lifespan of a building the service lifespan is meant. The time the building is in use including the duration of the next use. This is the same as the functional life.
Life cycle	Consecutive and interlinked stages of a product, service system, or building, from design, acquisition of raw materials, production, distribution, use and end-of-life management (Platform CB'23, 2019, p. 9)
Modular construction	Modular construction means that factory-built elements are used on the construction site. These elements often consist of several modules. And these modules contain various industrially manufactured components (Platform CB'23, 2019)
MPG	Environmental performance buildings (MilieuPrestatie Gebouwen; MPG) is a measure of the sustainability of a building in terms of (net) energy consumption and the environmental impact as a result of the use of materials. This is calculated in accordance with the assessment method managed by the Construction Quality Foundation (SBK) and summarized in the environmental cost indicator (MKI) score. An MPG is required for new-build homes and office buildings of 100+ m2 when applying for an Environmental Permit.
Non-renewable resource	Is a resource that is not of biological origin, or that it is of biological origin, but is not extracted, managed and / or grown without depleting the ecosystem concerned (Platform CB'23, 2019, p. 11)
Product-as-a-service	Is a revenue model in which the use of a product-as-a-service is offered. Ownership of the product thus remains in the hands of the service provider (Platform CB'23, 2019, p. 12)
Raw material	A raw material is a raw, unprocessed material that can be converted into a material. A distinction is made between renewable, organic raw materials (example: wood) and technical raw materials (example: iron ore) (Platform CB'23, 2019, p. 12)
Recover	Incineration of materials with energy recovery (Potting et al., 2017, p. 5)
Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality (Potting et al., 2017, p. 5)
Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials (Potting et al., 2017, p. 5)
Refurbish	Restore an old product and bring it up to date (Potting et al., 2017, p. 5)
Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product (Potting et al., 2017, p. 5)
Remanufacture	Use parts of discarded product in a new product with the same function (Potting et al., 2017, p. 5)
Repair	Repair and maintenance of defective product so it can be used with its original function (Potting et al., 2017, p. 5)
Repurpose	Use discarded product or its parts in a new product with a different function (Potting et al., 2017, p. 5)
Rethink	Make product use more intensive (e.g. by sharing product) (Potting et al., 2017, p. 5)
Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function (Potting et al., 2017, p. 5)
Sustainable development	Is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987, p. 49)
Upcycling	Process of converting secondary raw materials (by-products) into new materials, components or products of better quality, improved functionality and/or a higher value (Platform CB'23, 2019, p. 14)
Waste	Anything for which the generator or holder has no further use and which is discarded or is released to the environment (Platform CB'23, 2019, p. 14)

Table 6 – Glossary

Appendix B – Thesis scheduling & risks

B.1 Thesis scheduling

The project is divided into 6 work packages. The different work packages have related deliverables, milestones and potential risks, these are presented in the table below. The planning related risks are considered in the planning. Examples of mitigation measures were, relatively much time reserved for the execution of interviews, and buffers in the planning. The full risk register is presented in appendix B.2.

The research was executed in 7 months, from February 17th 2020 till September 29th 2020. The first 1,5 month was used for literature study and the development of the research proposal. The remaining 6,5 month were used for the execution of the remaining literature study and the development of the decision support tool and this thesis document. The scheduling of the tasks is in line with the CME2000 guideline for graduation theses and agreements during consultation meetings. Given multiple public holidays and the corona virus, the dates have shifted during the process. At the end, the major milestones were scheduled at the following days:

- The kick-off – 7th of May, 2020
- The mid-term – 30th of June, 2020
- The green light – 7th of September, 2020
- The thesis delivery – 22th of September, 2020
- The defence – 29th of September, 2020

Work package	Deliverables	Milestone	Risks
Kick-off	• Research proposal	Kick-off meeting	• Scope creep • Schedule mismatch of committee members • Misalignment expectations
			
Data gathering	• Literature study • Interviews	Mid-term meeting	• Non-provision of data / unavailability of interviewees • Scope creep • Schedule mismatch of committee members • Misalignment expectations
			
Analyse	• Analysis of the data	Mid-term meeting	• Schedule mismatch of committee members
			
Conclude	• Answers to research questions	Green light meeting (draft version)	• Conflicting outcomes analysis • Schedule mismatch of committee members
			
Validate and recommend	• Validated results • Recommendations	Final version	• Conflicting outcomes analysis
			
Present	• PowerPoint presentation	Presentation	• Schedule mismatch of committee members

Table 7 – Work packages with deliverables, milestones and correlating risks

B.2 Risk register

#	Cause*	Risk event**	Consequence	Prob-ability	Impact quality	Impact time	Mitigation measures	Prob-ability	Impact quality	Impact time	Secondary risk
1	Due to more knowledge and insights, adapting scope is necessary	Scope creep	More time required or reduced quality	C	3	3	Remained focus on defined scope and main research question. Alignment of expectations	D	2	2	Some flexibility will still be needed to adapt to the dynamics
2	Full schedule of graduation committee	Schedule mismatch of committee members	Delay of thesis planning	A	1	3	Plan important milestones after kick-off	D	1	3	
3	Different background and interests of involved parties	Misalignment expectations	Own and other expectations are not met	C	4	4	consultation initial research phase, send updates to graduation committee, take minutes on key meetings	E	4	4	
4	Dependency on external resources for data acquisition (unavailability interviewees)	Non-provision of data	Delay or reduced quality because of less data or longer data gathering phase	B	2	3	Schedule dates early and plan a buffer	D	2	3	If appointments are made early, they might be forgotten
5	Outcome empirical research is still unknown	Conflicting outcomes analysis, empirical and theoretical results	Extra work in order to explain outcomes	D	3	2	Extensive literature review, analysing data while gathering, schedule buffer	E	3	1	
6	Tight planning over relatively long time span and a worldwide epidemic	Illness can occur	Delay of thesis planning	B	1	3	Minimize contact and in case of illness immediate response	C	1	3	

* Cause, must be a fact

** Risk event, something that might happen, risks must be monitored throughout the research

Level	Descriptor	Description
1	Insignificant	No delay, minor impact on quality
2	Minor	1-2 weeks delay, minor impact on secondary quality criteria
3	Moderate	2-4 weeks delay, minor impact on overall quality
4	Major	4-6 weeks delay, impact on key quality criteria
5	Catastrophic	More than 6 weeks delay, significant impact on key quality criteria

Level	Descriptor	Description
A	Almost certain	Expected to occur in most circumstances
B	Likely	Probably occurs at some time
C	Moderate	Should occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur only in exceptional circumstances
F	Never	It is unforeseeable that this will occur

Figure 53 – Risk register

Appendix C – Interviewed experts

In the table below a complete list of all interviewed experts are given. Their perspective, current function, expertise and relation to the circular built environment is briefly explained. The type of company is also given. The names are fingered because of privacy reasons.

#	Name / perspective	Current function	Expertise	Years of experience	Type of company
1	Architect 1	Architect/ director architecture firm	Architect 1 is the owner of X. X is an interdisciplinary design studio for interior, architecture and urban design. Driven by a fascination for aesthetics with substance, the office strives to generate works that transcend the spatial by creating social, ecological and economic value. He designed, among other, the circular interior of HAKA and Circl Amsterdam. He is working on the circular, innovation pavilion in Almere. Besides, Architect 1 has been a professor sustainable architecture & urban redesign at the university of Rotterdam.	25+ years	Architect
2	Architect 2	Architect	Architect 2 is architect at X. X is an idealistic office, working towards a beautiful and circular world. Famous for circular designs such as 360 Rotterdam, museum Voorlinden, and City hall Venlo. She finished her architecture education in 1999. After that, she has been interested in and working on circular and inclusive designs.	20-25 years	Architect
3	Architect 3	Architect	Architect 3 is an architect at X. He worked, among others, on the famous completely detachable tijdelijke rechtbank Amsterdam. Joost studied building technology at Delft University of Technology and has been awarded several prizes: Jonge Architectenprijsvraag 2005 and 2007. In X he is valued for its innovative and technical solutions.	20-25 years	Architect
4	Architect 4	Architect	Architect 4 is an interior architect at X. She mainly focuses on interior design. Within this practice, she is searching for sustainable solutions in which circularity plays a role	0-5 years	Architect
5	Architect 5	Architect	Architect 5 is an architect at X. He is specialized in 'the new way of building' where co-creation and sustainability pressures come to innovative designs. He co-authored the book 'Alle dagen duurzaam - op weg naar een circulaire economie' and is working on projects like Drenthe Woont Circulair, modular dwellings in Wuppertal Germany, and circular dwellings in Stroinkslanden.	25+ years	Architect
6	Architect 6	Architect	Architect X is an architect at X. He is an all scale level architect with 17+ years of experience. He was involved in the circular projects 'New World Campus, the Hague', 'Circular interior StanislasCollege, Rijswijk' and 'Circular gardenhouse, Rijswijk'. From his early designs on, he likes to work with reused materials. Next to his work as architect, he has been teacher and external researcher at the TU Delft.	15-20 years	Architect
7	Architect 7	Architect/ director architecture firm	Architect 7 is CEO and architect at X. X is an architecture firm that specializes in circular design. He sees architecture as more than designing the built environment, it is 'making-the-city' with cultural values, social structures and economic activities. This whole system has to be considered when designing a circular building. He was involved, among others, in	20-25 years	Architect

				the design of the circular hub 'De Mengfabriek' in Den Bosch.		
8	Client contractor 1*	/	Senior consultant stations, urban design & consultancy	Client / contractor 1 is senior consultant stations, urban design & consultancy at Arcadis. He has a background in finance and worked at Arcadis for over 25 years. He specialized in making complex real estate and spatial development (financially) transparent and clear for the parties involved. Client / contractor 1 is interested in new trends such as the circular economy and understand its financial implications on the built environment.	25+ years	Engineering & consultancy
9	Client contractor 2	/	Senior consultant corporate real estate	Client / contractor 2 is senior consultant corporate real estate. He has more than 20 years of experience as consultant in corporate real estate. He was, among others, the project lead at the refurbishment of the Arcadis office Amersfoort. This office received the prize for Healthy Urban Office 2018. This office has multiple circular elements. He has a background in technology management and real estate (TU Eindhoven).	20-25 years	Engineering & consultancy
10	Client contractor 3	/	Senior consultant Real Estate Design & Consultancy	Client / contractor 3 is senior consultant Real Estate Design & Consultancy. He has 25 years of experience as technical advisor in different engineering & consultancy firms. He and his team make conceptual, innovative and sustainable design for installations and energy services. He is an expert in measuring methods BREEAM, GPR and WELL. Client / contractor 3 is interested in the circular economy and tries to incorporate it in his projects in a profitable way.	25+ years	Engineering & consultancy
11	Client contractor 4*	/	Sustainability consultant	Client / contractor 4 is a sustainability consultant. Passionate about the sustainable built environment and the circular built environment.	0-5 years	Engineering & consultancy
12	Client contractor 5*	/	Senior project manager	Client / contractor 5 is a senior project manager with 25+ years of experience	25+ years	Engineering & consultancy
13	Client contractor 6*	/	Senior Project Manager in Area Development	Client / contractor 6 is senior Project Manager in Area Development. He has 40 years of experience with area development in the Netherlands and abroad. At an airport in the real estate development department and at an engineering firm	25+ years	Engineering & consultancy
14	Client contractor 7*	/	Consultant Energy Transition	Client / contractor 7 is consultant Energy Transition. 2,5 years of work experience and focusing his career on the sustainable built environment	0-5 years	Engineering & consultancy
15	Client contractor 8*	/	Program leader Circular Economy / project manager buildings	Client / contractor 8 is consultant at X. He is responsible for the development and implementation of the circular approach in building projects. Next to sharing his knowledge about the circular economy, he is project manager for various building projects	10-15 years	Engineering & consultancy
16	Client / contractor 9*		Team leader / project manager buildings	Client / contractor 9 has 10 years of experience with project management and consultancy in the field of housing and utility projects.	5-10 years	Engineering & consultancy
17	Client / contractor 10*		Head project management & consultancy team / project manager buildings	Client / contractor 10 is head project management & consultancy team. He has 25+ years of experience in different consultancy, project manager and team lead functions within the built environment	25+ years	Engineering & consultancy
18	Client / contractor 11*		Consultant business development	Client / contractor 11 is working for multinational and 'blue chip' clients mostly on industrial logistics and real-estate. Before working at X, he worked at the independent social organisation X to stimulate a sustainable built environment	0-5 years	Engineering & consultancy

19	Client / contractor 12*	Senior project manager	Client / contractor 12 is a senior project manager with more than 30 years of experience. Currently working on the development of multiple AZCs	25+ years	Engineering & consultancy
20	Client / contractor 13*	Secretary project management & consultancy	Client / contractor 13 is secretary project management & consultancy. She does not have technical background but a critical layman's look	0-55 years	Engineering & consultancy
21	Client 1	Transition manager circular economy	Client 1 is Transition manager circular economy in the province of Zuid-Holland. He is responsible for the transition to the circular economy for the province of Zuid-Holland. Before his career at the province, he worked for more than 16 years of the municipality of The Hague in various public roles.	15-20 years	Government
22	Contractor 1	Director Development	Contractor 1 is Director Development at X. In 2019 he was the winner of the Sustainable 50. In his career, he was involved and initiator of multiple circular and sustainable projects such as Alliander Duiven, De Groene Loper, and the Greenhous Utrecht. For his work to make the Dutch building sector more sustainable, he not only was winner of the Sustainable 50, he also won the Green Leader Award in 2016.	15-20 years	Contractor
23	Specialist 1	Research fellow / director urban design consultancy	Specialist 1 is, among other things, a research fellow working on the subject of circular economy at Technical University of Delft and AMS Institute in Amsterdam. She has a background in urbanism and has experience in both designing and researching complex urban issues. In addition to academic research, specialist 1 is an experienced urban designer. She is director of X, and urban design consultancy based in London and Rotterdam.	15-20 years	University
24	Specialist 2	Policy advisor market & entrepreneurship	Specialist 2 is a policy advisor market & entrepreneurship at the Royal Institute of Dutch Architecture (BNA). Last year he co-authored a whitepaper 'Circulair Succes' https://repository.tudelft.nl/islandora/object/uuid:%3A30ca5368-a1a3-410a-94fc-a08a875348cb . He has a large network of architects and he understands the market well.	15-20 years	Institution
25	Specialist 3	Consultant sustainable, architectural concrete	Specialist 3 is an expert in sustainable concrete. Currently working at X and X. She has a background in architecture. Aesthetics and technical issues have her attention and she enjoys deepening her knowledge in these matters. With her extensive knowledge about concrete, she advises about how to use concrete in your projects in a sustainable and circular way.	15-20 years	Consultancy
26	Specialist 4	Assistant professor	Specialist 4 is an assistant professor at Delft University of Technology. As environmental scientist, he has expertise in life cycle assessment (LCA) of building materials and of buildings, and indoor environment of dwellings. In line with his research, Specialist 4 has extensive knowledge about circular materials and how to measure it.	15-20 years	University
27	Specialist 5	Senior consultant Financial Institutions / Manager Real Estate Transactions	Specialist 5 is senior consultant financial Institutions / commission Manager Real Estate Transactions at Arcadis. Specialist 5 has 18+ years of experience working in the Real Estate and Construction industry in the field of Transactions and (re)Developments. He has extensive knowledge about the office building sector and worked with all relevant stakeholders: investors, lenders, developers and occupiers.	15-20 years	Engineering & consultancy

28	Specialist 6	Business Developer - Sustainability and Circular Economy - Real Estate Finance	Specialist 6 has over 13 years of experience within financial services in varying roles. Currently working on implementing sustainability and circular business models for clients in our commercial real estate and construction portfolio at X. She is a member of 'Expert Pool Duurzaam Zakelijk Vastgoed' from the Nederlandse Vereniging van Banken and the 'Transitieteam Circulaire Bouweconomie'. Specialist 6 has a master sustainable energy technology and innovation management at the Eindhoven University of Technology.	10-15 years	Bank
29	Specialist 7	Senior consultant Energy Transition in the Built Environment	Specialist 7 is senior consultant Energy Transition in the Built Environment at X. She has a background in mechanical engineering and building services. Due to her interest in sustainable solutions for building services. She co-developed the circulariteitsschijf. This is a tool to help make building services circular.	10-15 years	Engineering & Consultancy
30	Specialist 8	PhD candidate Circular Economy & EU Environmental Law	Specialist 8 has been a PhD candidate at the University of Utrecht. Her doctoral research focuses on European law regarding chemicals, products and waste with a view to the transition to a circular economy. Specialist 8 studied law at Utrecht Law College (cum laude) and completed two masters in Constitutional and Administrative Law with the specialization Environmental Law. Specialist 8 won first prize for both her master's theses at the IBR scriptieprijs 2018/2019. Both theses are about law and circular construction	0-5 years	University
31	Specialist 9	Program manager sustainable development	Specialist 9 is program manager sustainable development at the Royal Institute of Dutch Architecture (BNA). He organizes with his colleagues' activities focused on knowledge sharing about sustainable architecture. There is special attention for circular architecture and building materials. Before his work at the BNA, he was member of council at the municipality of Zwolle and was responsible for implementing the circular economy in public spaces.	15-20 years	Institution
31	Sustainability advisor 1	Senior consultant Natural Capital and Circular Economy	Sustainability advisor 1 is senior consultant Natural Capital and Circular Economy at Arcadis. He has in the past years been the co-author of several reports; such as 'Scaling the circular built environment', 'The Future of the European Built Environment' and 'Building value – a pathway to circular construction finance'. In his projects he develops and implements sustainability strategies for clients in the built environment and infrastructure.	10-15 years	Engineering & consultancy
32	Sustainability advisor 2	Cost & Sustainability consultant	Sustainability advisor 2 is a cost & sustainability consultant at X. In his current role, he applies the gained knowledge from his studies in Building Engineering and Construction Management & Engineering when conducting technical inspections of real estate assets and solving cost as well as sustainability issues related to large-scale new construction and renovation projects within the construction sector.	0-5 years	Engineering & consultancy
33	Sustainability advisor 3	Advisor Circular Building	Sustainability advisor 5 has his own company specialized into workshops about CE and provides consultancy work for clients about circular design. He is already working with circular construction since 2012.	25+ years	Consultancy

* Client / contractor 4-13 has participated in the validating workshop. Client/ contractor 1 has both participated in the workshop and has been a respondent for the semi-structured interviews

Table 8 – Background of interviewed experts

Appendix D – Interview templates

Appendix D provide an overview of the content of the interviews. D.1 explains the contents of the exploratory interviews. D.2 provides the interview script of the semi-structured interviews. D.3 explains the contents of the validating interviews, the validating workshop and the feedback from the validating workshop.

D.1 Exploratory interviews

Exploratory interviews should have a theme (Kvale, 2008). This means that the purpose of the interview should be clear. During this research, exploratory interviews were held in order to explore and define the problem which was needed to be solved, and the characteristics which are needed for the solution. Practically, that meant that the interviews were focused on the barriers of the implementation of CE in the building sector, and the possible enablers which could support the transition to a circular built environment. The interviews were prepared around this theme and the expertise of the interviewee to ensure relevant information was gathered (Kvale, 2008). The exploratory interviews provided insight in the practical problem.

D.2 Semi-structured interviews

Below the interview template is given. This is in Dutch because all interviewed experts are able to speak that language. The semi-structured interviews with the specialists often ended to have a different structure because a conversation emerged around their expertise

D.2.1 Interview script

Generieke informatie

- Noteren geïnterviewde, datum & tijd. Duur maximaal 1 uur
- Vragen of ik mag opnemen, jezelf voorstellen en de ander zich laten voorstellen

Dit interview wil ik gebruiken om een beter overzicht te krijgen welke maatregelen er genomen kunnen worden om een kantoor circulairder te maken en hoe deze het best gewaarborgd worden in het ontwerpproces. Mijn doel met mijn onderzoek is om circulair ontwerpen praktisch en begrijpelijk te houden zodat de OG en architect dezelfde taal spreken. Dit wil ik doen door inzichtelijk te maken wanneer in het proces welke maatregelen geïntroduceerd moeten worden. Dit resulteert in een 'circulaire praatplaat' met daarop een praktische voorbeelden van circulaire maatregelen (gecategoriseerd in thema's en wanneer ze in het ontwerpproces ter sprake moeten komen).

Introductie

In mijn onderzoek hanteer ik de definitie van CB'23 voor circulair bouwen. Deze gaat als volgt:

Circulair bouwen is het ontwikkelen, gebruiken en hergebruiken van gebouwen, gebieden en infrastructuur, zonder natuurlijke hulpbronnen onnodig uit te putten, de leefomgeving te vervuilen en ecosystemen aan te tasten door gebruik te maken van zoveel mogelijk hernieuwbare grondstoffen. Bouwen op een wijze die economisch, sociaal cultureel en ecologisch verantwoord is. Hier en daar, nu en later.

1. Kunt u zich in deze definitie vinden?

Vragen over het ontwerpproces

Een standaard ontwerpproces gaat volgens de fasen van de standaardtaakverdeling van het BNR, initiatieffase, SO, VO, DO, TO, UO.

2. Zou u het ontwerpproces anders inrichten als u als doel hebt een circulair gebouw te ontwikkelen?
 - a. Waar moet je extra op letten?
 - b. Of wat zijn de belangrijkste keuzemomenten in het proces?

Circulaire interventies

In een stedelijk gebied in Nederland gaat een kantoor ontwikkeld worden. Een kantoor toren van ongeveer 10 verdiepingen is nu het idee. Momenteel staat er niks op het stuk land wat hiervoor bestemd is.

Stel u wilt een in deze casus... (afhankelijk van interviewee)

- Een circulair kantoor ontwerpen;
- Een advies geven om kantoor circulairder te maken, of

- Een circulair kantoor wilt laten bouwen

3. Als het gaat over een circulair ontwerpen. Wat vind je dan belangrijke thema's?

Vooraf gedefinieerde thema's o.b.v. theorie, test ze bij experts

- Aanpasbaarheid (levensduur verlenging, flexibele functie, flexibele inrichting)
 - Materialen (efficiëntie, renewables, recyclen)
 - Losmaakbaarheid (DfD, demontabel, modulair)
 - Proces, andere denkwijze / businessmodellen / contracten
4. Wanneer in het ontwerpproces komen deze maatregelen m.b.t. circulariteit ter sprake?

D.3 Validating interviews

D.3.1 Validating interviews

At the beginning of the validating interviews, there is a short introduction of myself and the interviewee. Then the research is shortly introduced. Followed up with the presentation of the current version of the decision support tool. This was discussed. Adaptations to the decision support tool was made according to the feedback of the interview respondent.

D.3.2 Validating participatory workshop

In order to validate the decision support tool, a validating participatory workshop was held. This workshop had a duration of 1,5 hour and had 11 attendees (project managers in different projects and varying knowledge about circularity). The workshop started with a brief presentation of the research and the introduction of the decision support tool. Following the interactive part started. A case was introduced and the group was divided into two teams. These teams got the same assignment which is explained below. The workshop ended with a short presentation of each team of their results and a feedback moment. The assignment and the results are shown in the following paragraph.

Interactive part

Medium: MURAL online whiteboard

Attendees: 13 (two teams of respectively 6 and 7 members)

Assignment: Think about circular interventions for this case. Fill them in on your teams' tool. By means of putting them on post-its of the right colour (yellow: process, green: adaptability, purple: reusability, blue: materials)

Case: fictive office building

- Goal: efficient and sober office
- Client: wants an office as investment object and attaches great importance to circularity
- Floorspace: 10,000 m²
- Location: central Rotterdam
- Contract: DBM-contract (term of 50 years)
- Role attendees: lead project manager

Results participatory workshop

On the following pages the results of the two teams are shown.

Other feedback that was given was:

- The circular themes are useful and were not questioned (even though project managers like to question the principles)
- Choosing elements that are recognizable for most people involved in construction is good (shearing layers of Brand & the phases in the design process). It makes the tool intuitive and workable
- The tool is extensive. This is good, especially for specialist. However, it is not possible/desirable to focus on adaptability, reusability, materials, and process at the same time and sometimes paradoxically. Maybe it is an idea to make it clearer that setting ambitions / choosing circular focus influence these possibilities?
- Site does influence the design of an office. Smart earthmoving etc. also influences the amount of materials used.
- Managing ambitions is complex. It is also much about money and other interests.

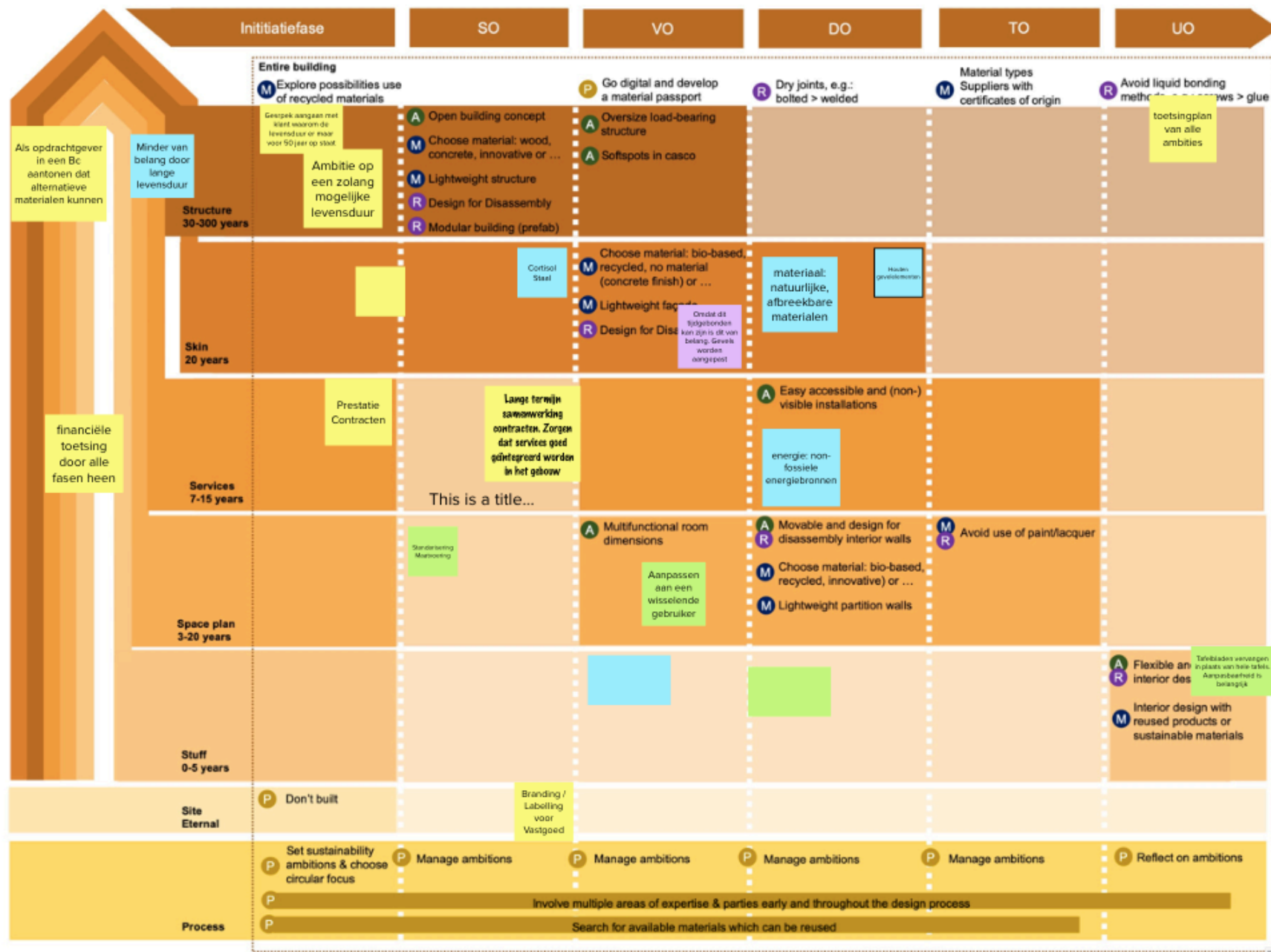


Figure 54 – Validating workshop team 1

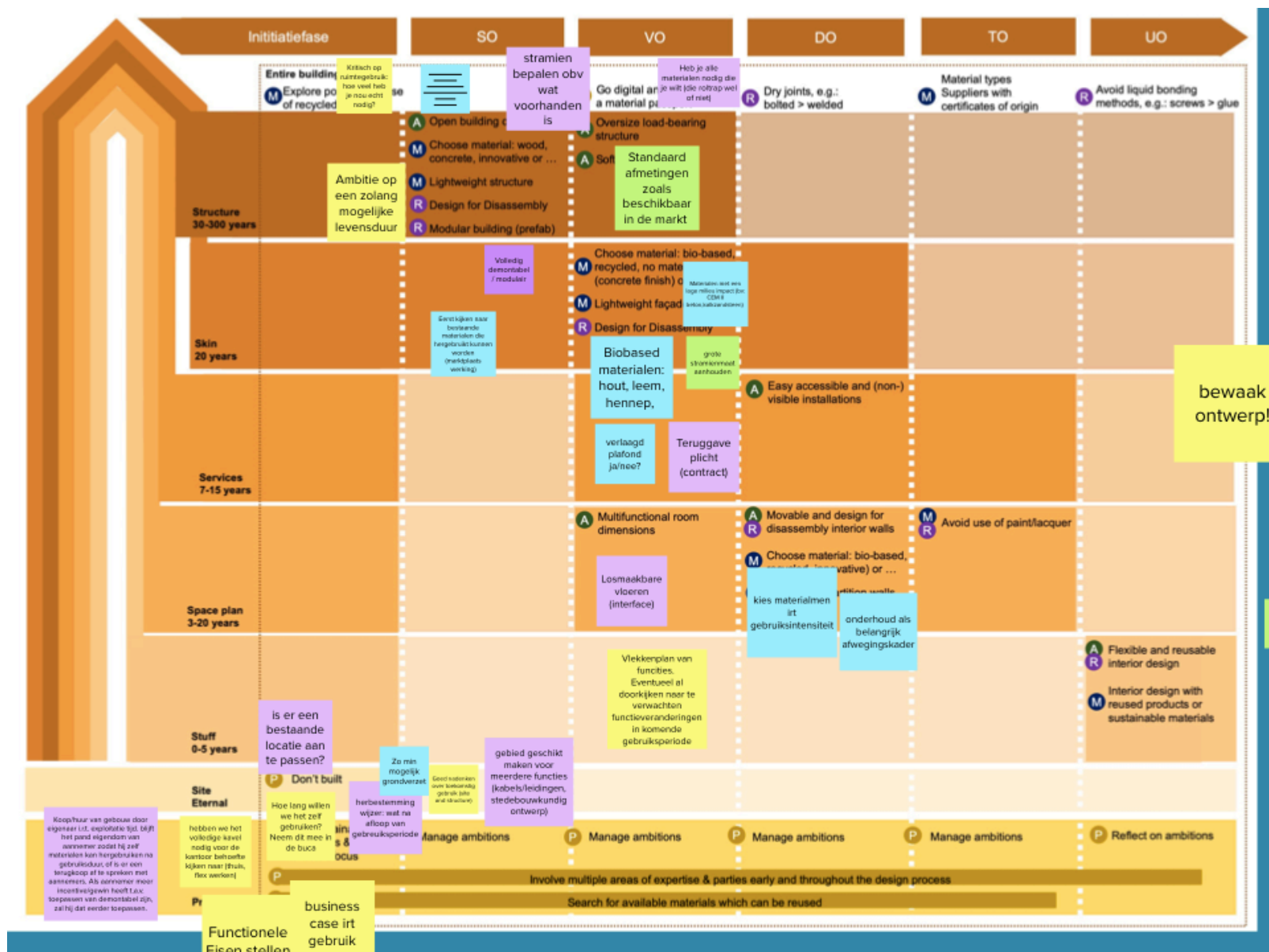


Figure 55 – Validating workshop team 2

Appendix E – Interview results

Through the knowledge of the interviewed experts, data for this research is acquired. Based on the interview template, knowledge about circular interventions and their placement in the design process was gathered systematically. As shown in the table below, some interventions are based on the expert knowledge of certain specialists and some are broadly supported among the interviewed experts.

Name intervention	Architect 1	Architect 2	Architect 3	Architect 4	Architect 5	Architect 6	Architect 7	Client / contractor 1	Client / contractor 2	Client / contractor 3	Client 1	Contractor 1	Specialist 1	Specialist 2	Specialist 3	Specialist 4	Specialist 5	Specialist 6	Specialist 7	Specialist 8	Specialist 9	Sustainability advisor 1	Sustainability advisor 2	Sustainability advisor 3	Total
Ambition																									
• Preconditions				1							1		1					1		1		1		1	7
• Sustainability aim		1	1								1	1	1					1				1			7
• Think outside the box		1									1	1	1					1		1		1		1	8
• Circular focus depends on project specific characteristics		1		1							1	1	1									1		1	7
People																									
• Broad collaboration & early involvement		1	1								1	1	1					1		1	1	1		1	10
• Creativity & teamwork		1	1								1		1								1	1			6
• Transparency		1									1	1	1												4
• Start search for suitable, second-hand materials early		1	1	1																	1			1	5
Schematic design																									
Go digital and develop a material passport						1	1													1					4
Open building concept	1						1																		2
Design for Disassembly	1	1	1									1												1	6
Modular building (prefab)				1			1				1														3
Lightweight load bearing structure					1																	1			2
Choose material load bearing structure																									
• Wooden structure					1		1			1															3
• Innovative material structure															1										1
• Recycled materials in the structure			1			1	1					1													4
• Sustainable concrete structure															1										1

Appendix F – Reference projects

In the first table below, the studied reference projects and their sources are shown. Most reference project are studied from media sources and literature. Information from some reference projects are gathered through interviews or talk shows. The table in E.2 describes the projects and their focus for this research. Moreover, each case is related to a circular theme, this is presented in appendix E.3.

F.1 List of reference projects with sources

#	Reference project	Year	Sources
1	Amsterdam International Community School (AICS)	2020	(de Meeuw, 2020; Duurzaam Gebouwd, 2019; Cirkelstad, 2020; DGBC, 2020)
2	Bicycle storage Eindhoven train station	2021	(Architecture Now, 2020; Architecten Cie, 2020; de Leeuw, 2020; Movares, 2020)
3	Canary Wharf Crossrail Station London	2021	(Crossrail, 2020; Grafton-Green, 2019; Young, 2020)
4	CIRCL Amsterdam	2017	(Architect 1, 2020; CIRCL, 2020; Ness et al., 2020)
5	City Hall Venlo	2016	(Architect 2, Wang et al., 2017; Gemeente Venlo, 2020; ExpoLAB, 2014)
6	Country house Zoutelande	2022	(Orio Architecten, 2018; Svarok, 2017)
7	HAKA building Rotterdam	1932	(Architect 1, 2020; DoepelStrijkers, 2011)
8	Headquarters Alliander Duiven	2015	(Contractor 1, 2020; BREEAMNL, 2013; Alliander, Boele & van Eesteren, VolkerWessels Vastgoed, Homij, RAU; Leising et al., 2018)
9	Hive Collingwood Melbourne	2020	(Hive, 2020; Spacestor, 2020)
10	Hive – Global Foods Innovation Centre Unilever Wageningen	2019	(Client / contractor 2, 2020; Unilever, 2020; BREEAM, 2019; Cobouw, 2017)
11	Innovation centre University of Santiago	2014	(Mairs, 2014; ArchDaily, 2014; Nyawara, 2017)
12	Mjøstårnet wooden office	2019	(Moelven, 2020; Thorns, 2018; Abrahamsen, 2017)
13	Natuurmonumenten Zierikzee	2019	(Specialist 3, 2020; ArchitectuurNL, 2019; Tilanus, 2017; 2018; Vissering, 2019)
14	Next21 Osaka	1994	(Habracken, 2003; van der Werf & Froyen, 1980; Lindner & Lendt, 2010)
15	Office MY DVA group Czech Republic	2016	(CHYBIK + KRISTOF, 2016; Kwok, 2017)
16	Office Triodos bank Zeist	2019	(Evers, 2019; Muis, 2019; Kanters, 2020; RAU, 2020)
17	Patch22 Amsterdam	2015	(FRANTZEN architects, 2017; Hannema, 2016; Bruning, 2013)
18	Temporary Courthouse Amsterdam	2016	(Architect 3, 2020; Cepezed, 2020; Nationale Staalprijs, 2018; Braendstrup, 2017; Crone, 2016; van Woerkom, 2016)
19	The Green House Utrecht	2018	(Contractor 1, 2020; Cepezed, 2018, AlbaConcepts, 2019; Vos et al., 2018)

Table 10 – List of reference projects with sources

F.2 Description reference projects

#	Project	Location	Year	Circular theme	Focus for this research	Description
1	Amsterdam International Community School (AICS)	Amsterdam, the Netherlands	2020	Reusability	• Modular building principles	A 100% modular building, it is a temporary school with the feel of a permanent building. It will be completely disassembled and reused 6 years later. The temporary school is 5,500m ² and supports 550 students. Designed by BurtonHamfelt Urban Architecture
2	Bicycle storage Eindhoven train station	Eindhoven, the Netherlands	2021	Materials Reusability Process	• Design with recycled materials • Prefab and DfD (temporary building) • Involving parties throughout the value chain • Close collaboration client architect contractor	Bicycle storage (5,000 bicycles) with facade from old train windows and the floors are partly made from wood from old trains. It is a temporary building made with prefab elements. The bicycle storage can be disassembled and has no underground storage and large foundations which increases the movability of the building. Building designed by Architecten Cie.
3	Canary Wharf Crossrail Station	London, England	2021	Materials	• Lightweight façade	The cross rail station is sitting below a 5-storey mixed-used development. The station is 250 meter long and has potential for extension. Facade was made from light, air-filled ETFE foil. Designed by Foster + Partners
4	CIRCL	Amsterdam, the Netherlands	2017	Materials Reusability Adaptability Process	• Wooden load bearing structure • Recycled materials • No stucco during construction (to protect the concrete floor) • Designed for disassembly (dry joints) • Visible and easily accessible services (no suspended ceiling) • Circular interior design • Pop-up restaurant (designed for disassembly, easy to reuse elsewhere) • Involving parties throughout the value chain • Close collaboration client architect contractor	Circular pavilion commissioned by ABN Amro and a showcase for the implementation of the circular economy in the building industry. The pavilion exists of 1,800m ² of office space and 1,200m ² of restaurant, bar, other. The main used material is wood (ea. the supporting structure) and much of the other materials are recycled. The building can be completely disassembled. Other circular interventions are also implemented in this pavilion.

5	City Hall	Venlo, the Netherlands	2016	Materials Reusability Process	• Demolition plan (everything is dismountable down to the chairs) • Entirely made of materials from C2C certified suppliers • Material passport • Circular interior • Movable interior walls • Involving parties throughout the value chain • Close collaboration client architect contractor	The city hall of Venlo is built according cradle-to-cradle principles. The office is CO2 neutral, Currently the office has 630 working spaces and 27,700 m2.
6	Country house	Zoutelande, the Netherlands	2022	Materials	• Bio-based façade materials	Traditionally looking building which is not traditional. The building is self-sufficient and made of bio-based materials such as wood, straw, loam, and lime. Designed by ORIO architecten
7	HAKA building	Rotterdam, the Netherlands	1932	Materials Adaptability	• Interior with reused products and materials from the region • Flexible interior (movable interior walls and furniture)	A renovated national monument. It was built as an office, factory and grain silo in the Rotterdam harbour district. Currently, it features a hub for modern craft businesses and catering establishments. The transformation of the building was a pilot for sustainable and circular interior design. Work was done with people without specific skills and a distance to the labour market.
8	Headquarters Alliander	Duiven, the Netherlands	2015	Materials Reusability Process	• Use of existing building (83%) • Use of recycled materials (e.a. (interior) facades of waste wood) • Material passport • Close collaboration client architect contractor • Co-creation between consortium and future users	Circular renovated office for over 1.550 employees. Maximal amount of the existing buildings is reused (83%), the demolition waste of the old concrete is reused in the new concrete, old doors are used for new furniture, and interior facades are made of recycled wood. These are some of the circular interventions. Next to that, the energy performance is substantially improved
9	Hive Collingwood	Melbourne, Australia	2020	Materials Adaptability	• Interior design with sustainable materials	1,300 m2 open-plan converted warehouse space. Currently the building houses different companies and freelancers who efficiently use the available office space. The interior is made of a mixture of bio-based and reused materials. The interior design is partly flexible and easily changed for changing demands.
10	Hive Global Foods Innovation Centre Unilever	Wageningen, the Netherlands	2019	Materials Reusability	• Circular interior from old furniture designed for disassembly • Use of recycled glass, aluminium and wood (90-95%) • Building elements are designed to be disassembled	Office and research lab with BREEAM outstanding certification. At completion it was the most sustainable, multifunction building in the world. Many interventions were implemented in order to achieve this level of sustainability such as; interior is made of furniture from three Unilever R&D locations, use of recycled materials and low energy use.

11	Innovation center University of Santiago	Santiago, Chile	2014	Materials	• Monolithic concrete finish	14-story building made of reinforced concrete with monolithic concrete finish and good natural cooling system. The monolithic concrete was the finish of the building (no extra materials needed for interior and exterior walls). Designed by ELEMENTAL.
12	Mjøstårnet	Brumunddal, Norway	2019	Materials	• Wooden load bearing structure • Wooden offices	At completion, the world's tallest timber tower. The tower is 85,4 meter and is located in Norway. The load bearing structure is made of glue laminated timber (glulam), this material stands up to steel structurally and has a lower carbon footprint. Moreover, glulam allows for more adaptability of the building due to the fact that larger spans without intermediate columns can be made. Designed by Voll Arkitekter
13	Natuurmonumenten	Zierikzee, the Netherlands	2019	Materials	• Application of warmbeton	Regional office of Natuurmonumenten in Zierikzee. The office is entirely built of thermal insulating warmbeton and glass. No other materials were necessary for insulation, partition walls, etc. The office was awarded the 'Betonprijs 2019'.
14	Next21	Osaka, Japan	1994	Adaptability	• Open building systems	An experimental 18-unit housing development using open building principles. The building is divided into two groups; long-life elements which are communal (load bearing structure) and short-life elements which are private (partition walls, installations, etc.). In such way the units can be easily adapted towards the individual needs.
15	Office MY DVA group	Vinohrady, Czech Republic	2016	Materials	• Recycled facade materials	This office is cheap renovation project. The building was an outdated car showroom. With the new facade made of old chairs gave it a luxury feel. Designed by SHYBIK + KRISTOF
16	Office Triodos bank	Zeist, the Netherlands	2019	Materials Reusability Adaptability Process	• Wooden load bearing structure • Prefab construction (less construction waste) • Circular interior • Material passport • DfD (only use of dry joints) • As-a-service façade • Movable interior walls • Involving parties throughout the value chain • Close collaboration client architect contractor	Sustainable and circular 5-storey office of the Triodos bank. The building is awarded with a BREEAM Outstanding certificate. The building can potentially 100% reused because it can be completely disassembled and properties are known in the BIM database. Next to circular and sustainability interventions, the building is built with the surrounding forest.

17	Patch22	Amsterdam, the Netherlands	2015	Materials Adaptability Process	• Wooden load bearing structure • Wooden building • Flexible floor plan (function change without changing structure) • Flexible installation due to hollow floors with removable top layer • Initiative from the architect, close collaboration client architect contractor	30 meter tall high-rise building in wood. Currently it is the tallest wooden building in the Netherlands. The first floor, core, and foundations are still made of concrete for the needed stability. Flexibility is created by gross floor heights of 4 meters and the ability to change the apartments into offices
18	Temporary Courthouse	Amsterdam, the Netherlands	2016	Reusability	• Design for disassembly (short term)	The goal of this project was to develop an entirely circular building. The client needed a courthouse for 5 years, after that period the building can be completely disassembled and assembled somewhere else. It was a DBMR contract, an integral approach where the contractor is responsible for the design, construction, maintenance and the removal or new purpose of the building. The contractor developed the building with a well adaptable configuration, thus facilitating changing uses and locations. Hence, the building can be easily assembled, disassembled and reassembled. The circularity of the Temporary Courthouse did not denigrate the quality, functionality or representativeness of the building.
19	The Green House	Utrecht, the Netherlands	2018	Materials Reusability Process	• Design for Disassembly steel skeleton with recycled panels and prefab concrete foundation and wooden elements • Recycled materials • Pay-for-use circular interior concept	Completely demountable, circular pavilion with urban farm, restaurant and meeting centre. The Green House is a temporary building, the final zoning plan of the area will be determined in 2030. The building is designed for disassembly, including the prefab concrete foundation. Recycled materials are used in surplus. An urban farm of 80m2 is also incorporated into the building. Interior is according a pay-for-use concept

Table 11 – Description reference projects

F.3 Reference projects in relation to the circular themes

	AICS (modularity)	Bicycle storage Eindhoven	Canary Wharf Crossrail Station (façade material)	CIRCL	City Hall Venlo	Country house (building materials)	HAKA building (interior)	Headquarters Alliander	Hive Collingwood (interior)	Hive Global Foods Innovation Centre	Innovation center University of Santiago (façade material)	Mjøstårnet	Natuurmonumenten (warmbeton)	Next21 (open building concept)	Office MY DVA group (façade material)	Office Triodos bank	Patch22	Temporary Courthouse	The Green House
Adaptability																			
Plan for change	✓	✓		✓	✓		✓			✓		✓		✓			✓	✓	✓
Design for long-life				✓	✓					✓		✓		✓			✓		
Design for loose-fit				✓	✓		✓		✓	✓		✓		✓	✓				✓
Reusability																			
DfD deconstruction	✓	✓		✓	✓		✓		✓									✓	✓
DfD connections	✓	✓		✓	✓		✓	✓		✓		✓		✓	✓		✓	✓	✓
DfD standardization	✓									✓		✓		✓			✓	✓	
Materials																			
Reduce materials		✓	✓	✓	✓			✓		✓	✓		✓						✓
Reused materials		✓		✓	✓		✓	✓	✓	✓					✓				✓
Bio-based materials				✓	✓	✓	✓	✓	✓	✓		✓					✓		✓
Process																			
Circular ambition		✓		✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓
Business model	✓			✓			✓			✓								✓	
Contract		✓		✓	✓		✓	✓		✓							✓	✓	
Broad collaboration		✓		✓	✓	✓	✓	✓		✓		✓	✓	✓			✓	✓	✓
Early involvement	✓	✓		✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		✓	✓	✓

Table 12 – Reference projects in relation to the circular themes

Appendix G – Example of application decision support tool

In this appendix a fictive project will be discussed. In this fictive project Windows for Circularity, the decision support tool, is used. What happens in every stage of the design process is explained. Note that this is an example and that the tool can be used in different ways if that suits better the project needs.

G.1 Initiation phase

In the initiation phase the feasibility and demand are analysed. Therefore, a workshop was held with all the involved parties based on the decision support tool. The aim of this workshop is to explore the possibilities of CE in this project and form ambitions. The workshop was as follows. Prior to the workshop, the attendees received a document with an explanation of CE and of the tool combined with a description of the circular interventions presented in the tool. Hereby, the attendees required knowledge about what CE entails and what practical examples of CE existed. During the workshop, the possibilities were discussed and plans were suggested how this building is going to be designed and how this related the circularity of the building. This resulted in workshop results as described below (in the format of the description in paragraph 5.5, interventions in the initiation phase) and the filled in decision support tool is on the next page (figure 56).

Don't build

Question whether this building really needs to be built

- In the end it was concluded that the office building is necessary to fulfil in the demand of office space and would gain the desired profit

Ambition

First the project ambitions are established.

- **Preconditions**
 - Time: bit below average. 2,5 years (initiation phase till building completion)
 - Money: bit above average. 1,300 €/m² gross floor area, (6,000*1,300=) 7.8 million € (cost excludes land purchase, fees and VAT)
 - Scope: 30 m tall high-rise office building, 8 storeys, 6,000 m² gross floor area
 - Quality: luxury office building with high sustainability score
- **Sustainability aim**
 - Energy neutral
 - Bio-based building (health & circularity)
 - The building should classify as a circular building
 - BREEAM excellent or outstanding
- **Think outside the box**
 - Explore possibilities. Contract with early involvement of contractor, searching for other forms for value than money, work with disabled people to reduce manufacturing costs
- **Circular focus**
 - **Adaptability.** Adaptable building is desired. Robust structure with flexible infill
 - **Reusability.** Reusable parts of the building. It would be nice if the load bearing structure is designed for disassembly, but it is not a must. Detachable building components in the infill of the building is desired
 - **Materials.** Focus on bio-based building, a wooden building is desired. Reused materials can maybe be used in the interior design and the façade made of reused wood is an idea
 - **Process.** The client is not eager to work with new business models but broad collaboration is desired

People

Then decisions about people management are made.

- **Broad collaboration & early involvement**

The following parties are going to be involved early in the design process: client, designers (architects, engineers, installation technicians), suppliers, (sub)contractors, demolition contractor, investors, government representatives, specialists (legal and financial)
- **Creativity & teamwork**

In every stage a workshop is organised based on the decision support tool with the involved parties (see broad collaboration & early involvement)
- **Transparency**

Transparency about the project budget is an aim. Then there is possibility to share risks and openly discuss how the best solutions can be found within the financial budget
- **Start search for suitable, second-hand materials early**

Start search for suitable second-hand wood for the façade in the beginning of the design process. From the technical design onwards the search for materials for the interior design will start

G.2 Schematic design

In the schematic design the requirements of the client, the possibilities and limitations of the site, and the environmental factors, are combined and translated in the first drawings. A new meeting is held with the project management team and the architect. The aim of this meetings was to make the first circular decisions based on the ambitions formed in the first session and limiting factors. The decisions are focused on the layers structure and skin. Inspiration for possible circular interventions in those layers are drawn from paragraph 5.6, interventions in the schematic design. The conclusions of this meeting is described below.



Agreements in regard to the design (related to CE)

Entire building

- Agreements are made that a material passport will be developed

Structure

- Open building concept
- Wooden load bearing structure. Due to budget constraints, the foundation and elevator shafts will still be made of concrete. The structure itself will be thick enough to suffice the safety requirements

Skin

- Modular infill. 3 sizes of modules which could be completely disassembled and have standardized dimensions. The first floor will not be consists of separate modules but will function as reception hall, restaurant, and meeting place.
- Wooden façade, preferably from waste wood

Site

- Earthmoving on site can be minimized by temporarily storing earth on nearby site. Agreements made with contractor

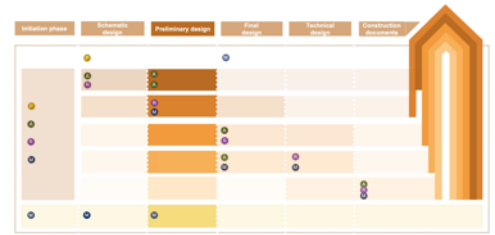


Figure 57 – First sketch of this fictive project (project photo of Patch22 (FRANTZEN architects, 2017))

Ambitions	Status schematic design
Building easy to adapt to changing functions or needs	✓
Infill completely designed for disassembly	✓
90% of the building mad of wood or reused materials (excluding installations)	Adjustment to 80%
Preconditions	
• Time: +/- 2,5 year • Money: 7,8 million euro • Scope: 6,000 m² GFA, 7-storey office • Quality: luxury office with high sustainability level	• Time: ✓ • Money: ✓ • Scope: ✓ • Quality: ✓
Sustainability aim	
• Energy neutral • Bio-based building • Circular building • BREEAM excellent or outstanding certificate	• Energy neutral: ✓ • Bio-based building: ✓ (excluding foundations & elevator shafts) • Circular building: ✓ • Adjustment to BREEAM excellent
Process	
• Involvement multiple stakeholders • Business models • Contract that stimulates CE	• The following stakeholders are going to be involved early in the design process: client, designers (architects, engineers, installation technicians), suppliers, (sub)contractors, demolition contractor, investors, government representatives, specialists • Business models: look into possibilities circular lease agreements for interior design or installations • Contract: DBM

G.3 Preliminary design

The preliminary design is the first spatial and aesthetic elaboration of the project. A meeting was held with the project management, architect, engineers, and installation technicians. The aim of this meeting was to take decisions in order to achieve the ambitions. The proposed interventions are no longer exploratory, they are practical solutions. In this stage, the focus is on multiple building layers. The focus was on the following layers; structure, skin, services, and space plan. Inspiration for possible circular interventions in those layers are drawn from paragraph 5.7, interventions in the preliminary design. The conclusions of this meeting is described below.



Agreements in regard to the design (related to CE)

Entire building

- Reduce material use. No escalator but an staircase (elevators available), parking space is available in the neighbourhood so no underground parking lot.
- Material passport. The first version of the BIM model has been made

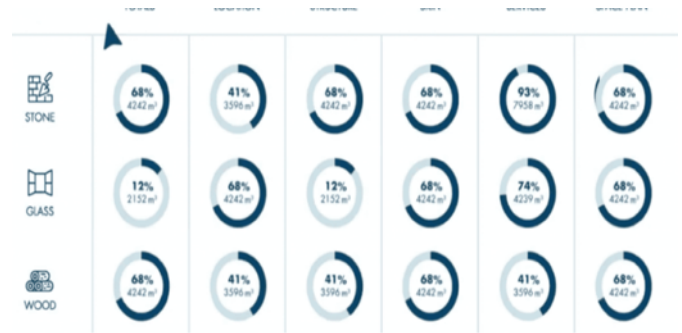


Figure 58 – Example of how information from BIM model can be transported to material passport (Wieldraayer, 2019)

Structure

- Supports multiple functions and uses because of over dimensioning
- Oversizing load bearing structure
- Large grid size and high ceilings:
 - Royal ceiling height of 4 meters to increase luxury of the office building and make the building more adaptable to change.
 - Large grid size
- Softspots: there is the possibility to later built staircases to connect floor 1 and 2 (two separate reception halls) and floor 5 and 6 (larger space possible without using the main staircases)

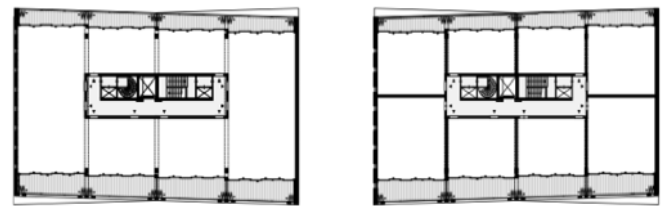


Figure 59 – Large grid size fictive building. Left space plan without division walls, right space plan with maximum number of division walls (figure from FRANTZEN architects (2017))

Skin

- Façade should be able to be (partly) disassembled and should be able to adapt for changing needs
- The use of waste wood is more difficult than expected, therefore a design with reused wood and green panels has been chosen. In the length of the building and on the first floor, large windows are placed next to this façade design

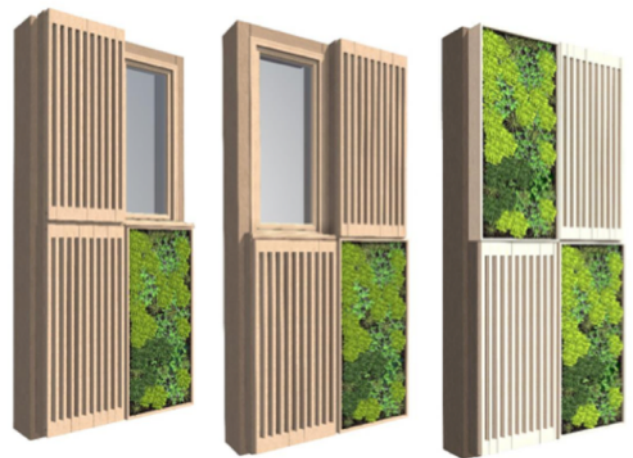


Figure 60 – Building facade made of DfD reused wood panels and green panels. In order to change to adapting needs, the panels can be separately changed (figure from Durmisevic et al. (2019))

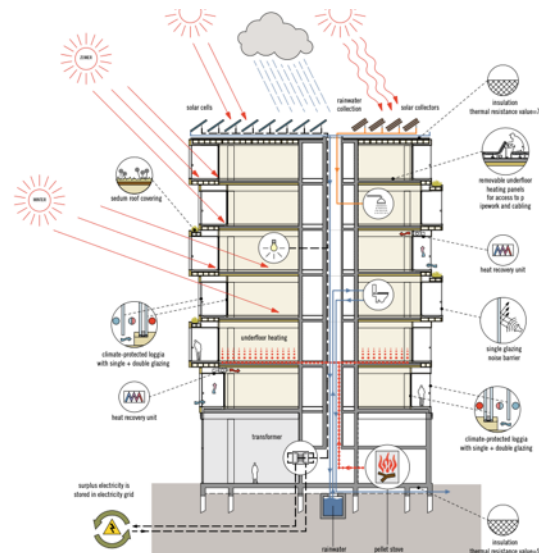


Figure 61 – Heating and cooling plan fictive building, includes solar cells and collectors, rainwater collection, removable underfloor heating and cables in hollow floor slabs, climate proof loggias (figure from FRANTZEN architects (2017))

Services

- Installation plan. Optimal trade-off between energy efficiency and materials used estimated
- Idea of hollow floor slabs with removable top layer in order to make it easier to replace and repair services

Space plan

- Multifunctional room dimensions. Three sizes modular rooms are developed. The space plan could be suitable for an office building, but also for a school, hotel rooms, and apartments
- Standardization of building components, all prefab
- Increased flexibility of space plan by having the piping and cabling horizontally, hence only one vertical shaft in the core

Ambitions	Status preliminary design
Building easy to adapt to changing functions or needs	✓
Infill completely designed for disassembly	✓
80% of the building mad of wood or reused materials (excluding installations)	✓
Preconditions	
• Time: +/- 2,5 year • Money: 7,8 million euro • Scope: 6,000 m² GFA, 7-storey office • Quality: luxury office with high sustainability level	• Time: ✓ • Money: cost increase, current estimate of 8 million euro • Scope: ✓ • Quality: ✓
Sustainability aim	
• Energy neutral • Bio-based building • Circular building • BREEAM excellent certificate	• Energy neutral: ✓ • Bio-based building: ✓ (excluding foundations & elevator shafts) • Circular building: ✓ • BREEAM excellent: ✓
Process	
• Involvement multiple stakeholders • Business models • Contract that stimulates CE	• Involvement multiple stakeholders: ✓ • Business models: no leasing of installations, maybe circular performance contract for interior design • Contract: DBM

G.4 Final design

After all feedback is incorporated and all adjustments are made to the preliminary design, the final design will be developed. All spatial relations and the materials are determined. In this stage, multiple meetings with specialists were being held in order to achieve the ambitions. The decision support tool including the project specific ambitions functioned as an overview for the project management team. The focus was on the layers skin, services, and space plan. Inspiration for possible circular interventions in those layers are drawn from paragraph 5.8, interventions in the final design. The decisions taken in this stage and are related to CE are described below.



Entire building

- Accessible connections
- Appropriate joinery by using dry joints. Bolted in favour of welded connection. Screws in favour of glue and nails
- Use of CLT and Glulam wood
- Materials from suppliers with certificate of origin. This earns extra points for the BREEAM certificate, however it is expensive. But it is feasible because a BREEAM outstanding certificate can be obtained
- Information updated in material passport

Skin

- Detailing of façade in order that only dry joints were made

Services

- Improvement installation plan.
- It was difficult to use reused installations or DfD installations. Therefore, it is chosen to install new installations.
- The installations however, will be easily accessible. Hollow floor slabs with removable top layer in order to make it easier to replace and repair services

Space plan

- Wooden, prefab interior walls
- Interior walls are detached without liquid bonding methods.



Figure 62 – Accessible and detachable wooden connection (Durmisevic et al., 2019)

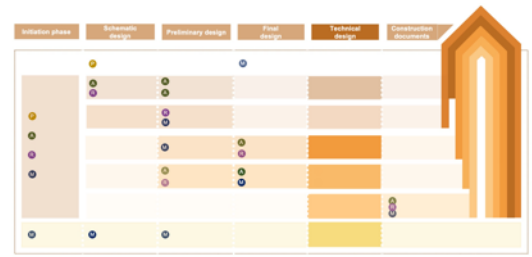


Figure 63 – Hollow floor slabs (picture from Patch22 FRANTZEN architects (2017))

Ambitions	Status final design
Building easy to adapt to changing functions or needs	✓
Infill completely designed for disassembly	✓
80% of the building mad of wood or reused materials (excluding installations)	✓
Preconditions	
• Time: +/- 2,5 year • Money: 8 million euro • Scope: 6,000 m² GFA, 7-storey office • Quality: luxury office with high sustainability level	• Time: ✓ • Money: cost increase, current estimate 8,5 million euro • Scope: ✓ • Quality: ✓
Sustainability aim	
• Energy neutral • Bio-based building (excluding foundations & elevator shafts) • Circular building • BREEAM excellent	• Energy neutral: ✓ • Bio-based building: ✓ • Circular building: ✓ • Adjustment back to BREEAM outstanding
Process	
• Involvement multiple stakeholders • Business models • Contract that stimulates CE	• Involvement multiple stakeholders: ✓ • Business models: maybe circular performance contract for interior design • Contract: DBM

G.5 Technical design

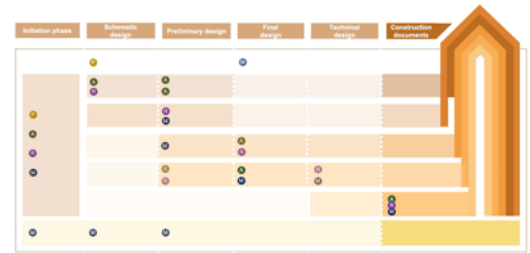
The technical design is even more detailed and the final pricing for construction will be determined. In this stage, there were not much new circular interventions taken. If new interventions were to be introduced, they would probably have been related to the building layers services, space plan or stuff. It was checked whether the previously made plans are correctly implemented. The decision support tool was used in this stage to evaluate the ambitions. A meeting was held to evaluate which of the ambitions were accomplished and which were not (figure 56). The conclusions of this meeting are described below.



Ambitions initiation phase	Status final design	Status technical design
Building easy to adapt to changing functions or needs	✓	✓
Infill completely designed for disassembly	✓	✓
90% of the building mad of wood or reused materials (excluding installations)	Adjustment to 80%	✓
Preconditions		
- Time: +/- 2,5 year - Money: 7,5 million euro - Scope: 6,000 m² GFA, 7-storey office - Quality: luxury office with high sustainability level	- Time: +/- 2,5 year - Money: 8,5 million euro - Scope: ✓ - Quality: ✓	- Time: ✓ - Money: 9 million euro - Scope: ✓ - Quality: ✓
Sustainability aim		
- Energy neutral - Bio-based building (excluding foundations & elevator shafts) - Circular building - BREEAM outstanding or excellent certificate	- Energy neutral: ✓ - Bio-based building: ✓ - Circular building: ✓ - BREEAM outstanding certificate	- Energy neutral: ✓ - Bio-based building: ✓ - Circular building: ✓ - BREEAM certificate: ✓
Process		
- Involvement multiple stakeholders - Business models - Contract that stimulates CE	- Involvement stakeholders: ✓ - Business models: maybe circular performance contract interior design - Contract: DBM	- Involvement stakeholders: ✓ - Business models: maybe circular performance contract interior design - Contract: DBM

G.6 Construction documents

In the last stage of the design process, the construction documents are developed. The construction documents are needed to construct the building. In this stage three meetings were held. One to evaluate the complete design process. One with the project management team and the contractor to ensure that no liquid bonding methods were used and to discuss how construction waste could be minimized. The other meeting is with the project management team and the interior designer. Inspiration for possible circular interventions for the interior design can be taken from paragraph 5.10 interventions construction documents. The conclusion of these meetings is described below.



Entire building

- Plan reduction construction waste
- Construction documents without liquid bonding methods

Stuff

- Circular performance contract desks and chairs
- Built in furniture made of reused materials
- Interior design is flexible and easily to moved, maintained or replaced

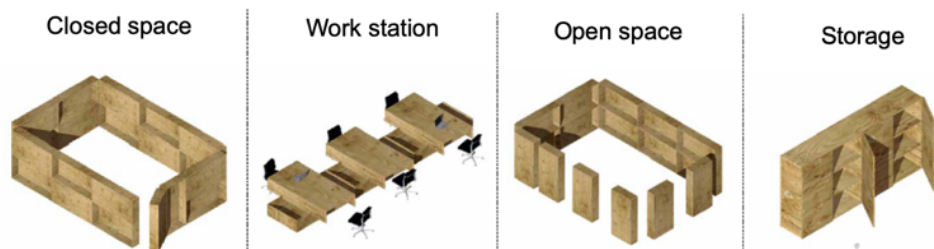


Figure 64 – Flexible and easily movable built in interior design made from second-hand wooden panels (figure from HAKA building DoepelStrijkers (2011))

Ambitions initiation phase	Achieved ambitions
Building easy to adapt to changing functions or needs	✓
Infill completely designed for disassembly	✓
90% of the building mad of wood or reused materials (excluding installations)	80%
Preconditions	
• Time: +/- 2,5 year • Money: 7,5 million euro • Scope: 6,000 m² GFA, 7-storey office • Quality: luxury office with high sustainability level	• Time: ✓ • Money: 9 million euro • Scope: ✓ • Quality: ✓
Sustainability aim	
• Energy neutral • Bio-based building (excluding foundations & elevator shafts) • Circular building • BREEAM outstanding or excellent certificate	• Energy neutral: ✓ • Bio-based building: ✓ • Circular building: ✓ • BREEAM outstanding certificate: ✓
Process	
• Involvement multiple stakeholders • Business models • Contract that stimulates CE	• Involvement multiple stakeholders: ✓ • Business models: circular performance contract for desks and chairs • Contract: DBM