Talking circularity - the influence of actors on the building process

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Talking circularity - the influence of actors on the building process

research part II

MSc thesis Delft University of Technology

Talking circularity - the influence of actors on the building process

A study into actor networks and influence on decision-making regarding the implementation of circularity into the building process.

This thesis was written in partial fulfillment of the requirements for the degree of Master of Science (MSc) for the master program Construction, Management and Engineering (CME) at the Faculty of Civil Engineering & Geosciences at Delft University of Technology.

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Preface

Before you lies the research report titled 'Talking circularity - the influence of actors on the building process'. This research report provides information on the topic of actor networks and actor's influence on decision-making regarding the implementation of circularity into the building process.

This research is part of a cross-disciplinary research for obtaining a double degree in 'Construction, Management and Engineering' (CME) at the Faculty of Civil Engineering and Geosciences and 'Architecture, Urbanism and Building Sciences' (ARCH) at the Faculty of Architecture. Previously, research has been conducted as part of the 'Architecture, Urbanism and Building Sciences' graduation program (part I). This thesis (part II) builds on the previous research and further explores circularity in building projects. Afterwards, a design (part III) will be made, which will use output from both theses as point of departure.

This research report has been written to fulfill the requirements of the MSc 'Construction, Management and Engineering' program. This research has been conducted under supervision of Prof.dr.ir. Hans Wamelink, Dr.ir. Els Leclercq, and Dr.ir. Hielkje Zijlstra. I have worked on this report from September 2018 to February 2019.

Ditte Gerding,

February, 2019

Summary

The building sector is responsible for a large share of the total waste production in the Netherlands. This is partly due to the organization of the building process, which follows a principle of constant production and consumption of (raw) materials. Currently, the design of buildings does not take into account the possibility to take them apart. At the end of a building's life time it is extremely difficult to reuse or recycle materials. This results in a lot of building components ending up as waste. The current pressing scarcity of resources and polluting influence of waste, requires a more circular building approach to support the need for sustainable building. The past years, circularity has become a popular term in the built environment. This approach prefers a more circular way of perceiving the building process. Literature indicates that implementation of circularity in the building process, probably, will require different actors to be involved and different decisions to be made.

The purpose of this master thesis is to gather information from current practices and make recommendations to facilitate implementation of circularity in the building process. The actors should contribute to implementation of circularity in the *beginning* of the building process preferably. In this phase, provisions can be made to minimize building waste at the end of a building's life. Besides, in this phase minimizing material use and use of secondhand components *upfront* can be secured and prepared for.

The following research method is adopted: a literature study, and case study research including interviews. This method helps to provide context for the analytical framework (literature study), which provides assessment criteria to evaluate current circular building projects (case studies), by which the case studies can be investigated (relying on data from the interviews), thereby recommendations for improvement can be provided. The literature study consists of: theory on the involved actors, theory on decision-making, and theory on implementation of circularity in relation to the building process. From this literature study, assessment criteria for the case study

research can be conducted. The case study research evaluates the actor network and decision-making processes based on three building projects. These projects are: Townhall in Brummen by RAU built in 2013; The Green House in Utrecht by cepezed built in 2018; and EDGE Olympic in Amsterdam by Architekten Cie. built in 2018.

This results in the following major findings. Both 'traditional' as well as 'circular-related' actors are involved in the building process of circular building projects. 'Traditional' actors are defined as actors from public or private parties. 'Circular-related' actors are defined as actors that contribute to implementation of circularity. The types of 'circular-related' actors involved in the actor networks of the cases are: transformation agents, circularity experts, dismantlers, reclamation experts, and a legal officer. In addition, some involved 'traditional' actors with 'circular-related' resources were identified (mainly suppliers, specialists, and subcontractors).

The actors part of the project team (thus generally 'traditional' actors) have a higher influence on decision-making regarding circularity than actors outside of the project team. Other actors, outside of the project team, could have influence on decision-making, but this is more in an indirect way. The 'circular-related' actors predominantly exert middle or little influence on the decision-making. Although these actors are involved in most decision-making (rounds) their influence on these decisions is, unfortunately, limited. For each case an actor (contractor, project manager, and client) was identified that stood out in terms of ability to inspire, initiate, support and accelerate implementation of circularity. This actor acted as transformation agent.

The analytical framework shows that circularity can serve different ends (reduce, reuse, recycle), of which 'reduce' is the preferred aim. In accordance with these ends, certain patterns can be chosen with accompanying circular strategies (CSs) and design strategies. These patterns can be applied as beginning and as end of life scenario for the building. The following patterns were identified: '[1] prevention & reduction'; '[2] repair & maintenance'; '[3] reuse & redistribution'; '[4] refurbishment & remanufacturing'; '[5] recycling'; '[6] cascading & repurposing'; '[7] organic feedstock'. In addition the following CSs were identified: 'maximize material and energy efficiency'; 'de-materialization'; 'functionality without ownership: product service system (PSS)'; 'extending product value'; 'classic long life model'; 'encourage sufficiency'; 'extending resource value'; and 'industrial symbiosis'. In addition, decisions regarding the following topics are of concern: 'waste handling and processing', 'maintenance & repair', 'take-back management', 'transport and logistics', 'acquire & procure', and 'information & documentation'.

The initiation and preparation phase offer important moments to decide upon beginning and end of life scenarios and thereby implement circularity. With respect to this, early on decision-making on circularity benefits its implementation in practice. In addition, the case study research concluded that particularly for the *long-lived layers* of the building early on decision-making is beneficial for implementing circularity in practice. Later on in the building process, after initiation and preparation (and design) phase, proper implementation of long-lived layers and subsequent CSs and design strategies is difficult.

This thesis concludes that circular-related actors and traditional actors with circular related resources should be involved and be influential in decision-making in the building process of circular building projects. This study particularly demonstrates the benefit of early on involvement of the following circular-related actors: transformation agent, circularity expert, reclamation expert, dismantler, and legal officer. In order to increase their influence on decision-making these actors should become part of the project team, or at least be taken seriously and offered room to influence decision-making. Especially, if traditional actors lack knowledge and resources for implementing circularity. Moreover, contribution of their resources regarding circularity is facilitated, if these actors are involved early on. Thus, involvement of circular-related actors and traditional actors with circular-related resources early on and subsequent ability to influence and contribute to decision-making, facilitates implementation of circularity in the building process.

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1. Introduction

1.1 Context

The building sector is responsible for a large share of the total waste production in the Netherlands. This is partly due to the organization of the building process, which follows a principle of constant production and consumption of (raw) materials. The linear production of buildings entails the stages of design, construction, consumption and demolition, or in other words follows a 'take, make, waste' process (Mcdonough & Braungart, 2009). This process opts for constant utilization of raw materials, since a building is not designed to be demountable. In the Netherlands, at the end of a building's lifetime, only a small amount of the building materials and parts are reclaimed, a large amount is regarded as waste, see Figure 1.1 up to Figure 1.3 (Centraal Bureau voor de Statistiek, 2009).

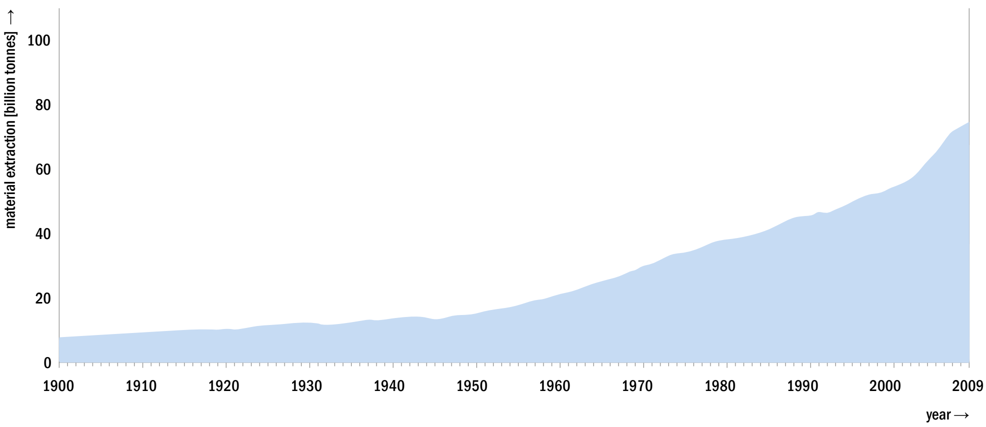


Figure 1.1 Global material extraction, extracted from Vidal-Legaz, B., Mancini, L., Blengini, G., Pavel, C., Marmier, A., Blagoeva, D., … Pennington, D. (2016). Raw Materials Scoreboard - European Innovation Partnership on Raw Materials. European Union.

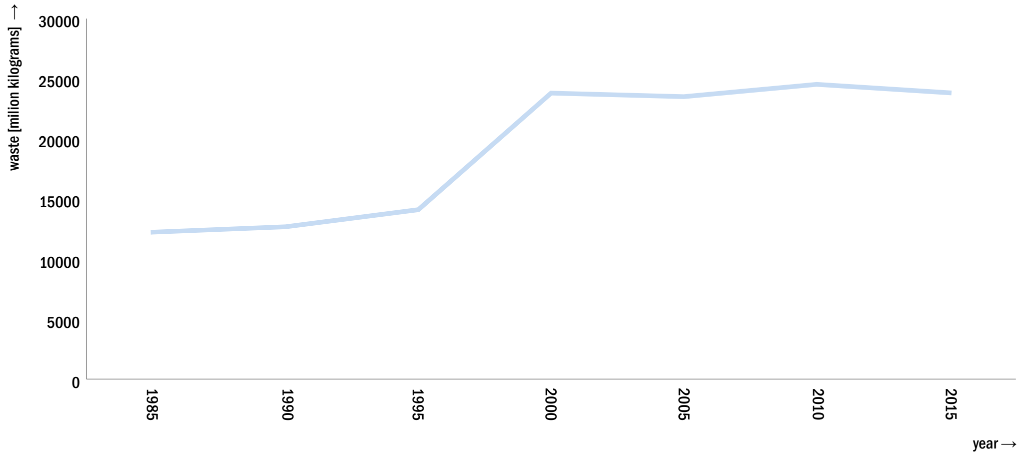


Figure 1.2 Waste production in the Netherlands, extracted from Rijkswaterstaat Leefomgeving, (2017). Vrijkomen en verwerking uit de doelgroep Bouw, 1990-2014.

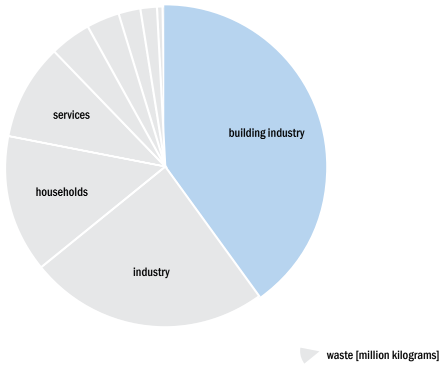


Figure 1.3 Waste production per sector in the Netherlands, extracted from Rijkswaterstaat Leefomgeving, (2017). Vrijkomen en verwerking uit de doelgroep Bouw, 1990-2014.

Currently, the design of buildings does not take into account the possibility to take them apart. At the end of a building's life time it is extremely difficult to reuse or recycle materials. This results in a lot of building components ending up as waste. The current pressing scarcity of resources and polluting influence of waste, requires a more circular building approach to support the need for sustainable building.

Several ways to reshape the linearity of the building process towards a more circular process have been invented and applied in successful or less successful ways. Some approaches have focused on cutting down production and consumption rates. Other approaches have focused on building with waste (Mulhall & Braungart, 2010). The past years, circularity has become a popular term in the built environment. This approach prefers a more circular way of perceiving the building process. By closing 'material cycles' this approach aims to deal more consciously with resources and materials and generally utilizes waste (that is generated after demolition) as a resource (Rau & Oberhuber, 2016; Mcdonough & Braungart, 2009). See Figure 1.4 for a schematic overview of a linear and circular building process. It must be noted that these building processes are somewhat simplified. As can be seen, a circular building process focuses on reducing waste and minimizing use of raw materials. It does so by means of prevention, reuse, recycling, or decomposition (in case of decomposable materials).

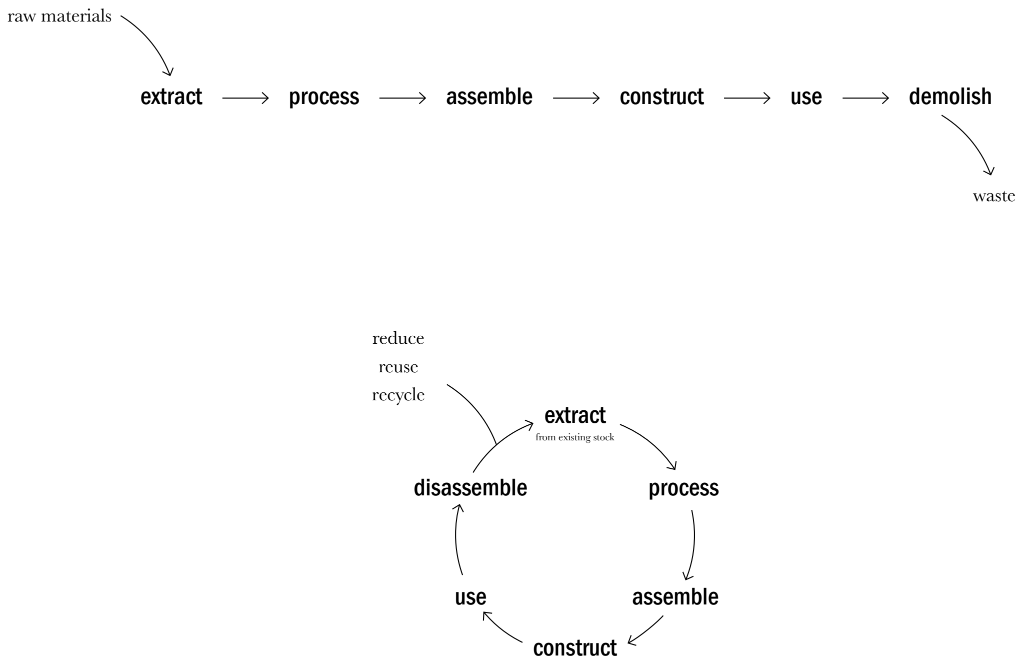


Figure 1.4 Linear building process (top) and circular building process (bottom) from the perspective of a building component, based on Durmisevic (2010) and Crowther (1999).

The previous research (part I) focuses on the concept of 'design for disassembly'. The term 'design for disassembly' relates to this circular building process. Instead of reducing or reusing waste, it aims to create less waste in the first place (Rau & Oberhuber, 2016). In the previous research (part I), based on a literature study, this concept is defined as: *"anticipating the temporality of a building by means of designing a building to be demountable, to be able to reuse or recycle building components, thereby reducing the need for raw materials and minimizing the generation of waste"* (Gerding, 2018, p.56). Design for disassembly can be consider as part of circularity, since it offers a certain design strategy to close material cycles. This research (part II) takes a broader perspective and focuses on the term circularity and it implementation in the building process.

This introduction continues as follows. First, a problem statement is provided, which identifies current issues and indicates the gap in the current literature. Second, the research question and accompanying sub questions are presented which build upon the research objective. Subsequently, the method in order to come to (desired) results is described. Fourth, the relevance for the research is provided. Last, the structure of this thesis is discussed.

1.2 Problem statement

Although circularity seems to be a promising concept, some difficulties appear to arise during its implementation. It seems that difficulties are mostly to be expected in relation to the process, and to a lesser extent in relation to the technicalities (Gerding, 2018). Technical possibilities to build and design in a circular way (already) exist. Additionally, from the previous research, it was concluded that the costs for building circular seem to be an important aspect that hamper implementation. Today, dismantling still requires more time and money than demolition. In addition, as became clear from this study, the collaboration between stakeholders in the building process, and especially how their roles should change, is of importance to secure implementation of circularity. In sum, difficulties in relation to the process, cost and time, and collaboration, hamper the implementation of circularity in practice.

It can be argued that these difficulties are inherent to the conventional organization of the building process. Adams, Osmani, Thorpe, & Thornback, (2017) indicate several barriers in this respect. These are amongst others: lack of awareness and knowledge of circular building processes that designers and clients have, a fragmented supply chain, and lack of considerations and incentives at the start and end phase of the building's life time (Adams et al., 2017). Unfortunately, this research only identifies challenges and enablers in the building process, and does not further explain or define these aspects.

In particular, the implementation of circularity should be improved at the start and at the end phase of the building's life time. It must be noted that beginning and end phase can be different for each building component, see Figure 1.5. As can be seen, a building's life time has a clear beginning and end point in time. It could be, however, that the building's components already had a life before and will have a life after the building's life time in another building.

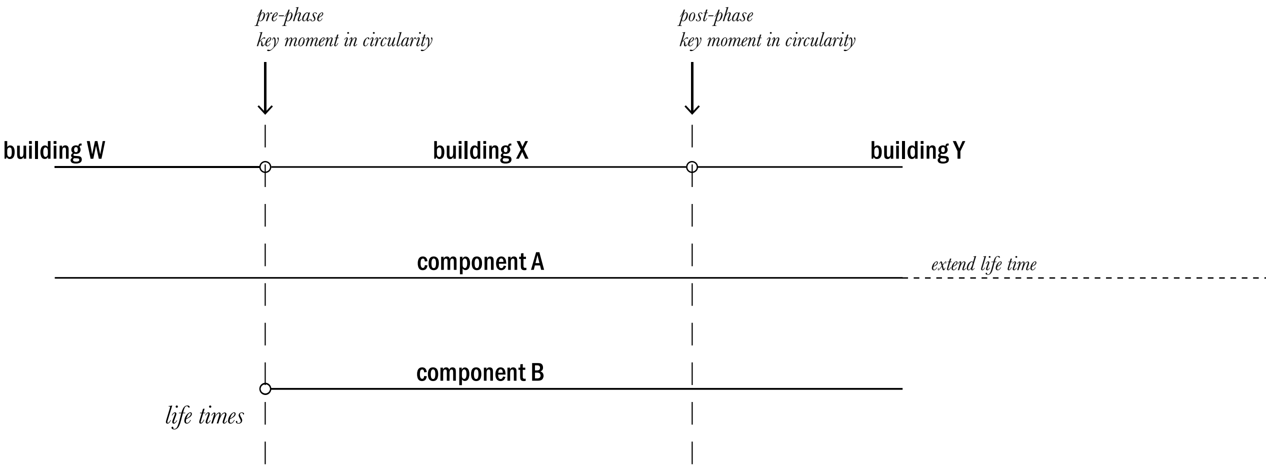


Figure 1.5 A building's life time and building component's life time. Generally, these life times do not match. The building component's life time, for instance, exceeds the building's life time. The component's life should become circular.

It can be considered that the 'start' and 'end' phase of the building's life time need to be reconsidered to obtain a circular process and close the cycle. Especially, the step from 'remove' to 'design' is difficult in practice. As can be seen in Figure 1.6, the start phase (or pre-phase) includes the implementation of already existing building components (secondhand materials). The post-phase should be designed to guarantee disassembly and reuse (or recycling) in the next building. Important to note is that preparations to guarantee dismantling and reuse can already be made during the pre-phase. So, in relation to the conventional building process, a circular process should include use of secondhand building components upfront and subsequently disassembly at the end of life and taking actions to prepare for reuse (and recycling) in another building.

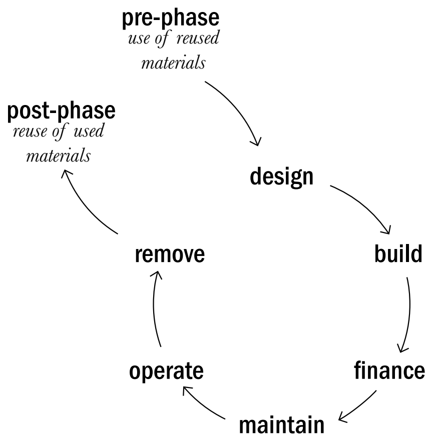


Figure 1.6 A circular building process including a pre-phase and post-phase, based on Durmisevic (2010) and Crowther (1999).

Literature indicates that implementation of circularity in the building process with respect to these phases, probably, will require different actors that should be involved and different decisions that should be made. Gorgolewski & Ergun (2013) explain that different relations should be established and other actors should be involved, such as demolition or salvage companies that could aid in sourcing reused materials (Gorgolewski & Ergun, 2013).

Therefore, the research objective is to gather information from current practice(s) and make recommendations for improving the actor network and the decision-making process to facilitate implementation of circularity in the building process. The actors should contribute to implementation of circularity in the *beginning* of the building process preferably. In this phase, provisions can be made to minimize building waste at the end of a building's life. Besides, minimizing material use and use of secondhand components upfront can be secured and preparations can be made for reuse of the used building components.

1.3 Research questions

Based on the problem statement and research objective, the following research question is formulated:

"Which actors should be involved (in the beginning of the building process) to ensure circularity (implementation of circular building) throughout all phases in the building process and which actors should influence decision-making?"

The following sub questions are formulated:

1.1. *"Which actors are involved in the building process of circular building projects?"*

This sub question identifies actors that are involved in the building process in circular building projects. It could be that additional actors, besides the conventional actors that are involved in a building process, are involved in the building process to secure implementation of circularity.

1.2. *"Which actors influence decision-making on circularity?"*

This sub question identifies which actors influence decision-making on circularity.

1.3. *"What decisions on circularity are made?"*

This sub question identifies important decisions that are or should be made to implement circularity.

1.4. *"When are decisions on circularity being made?"*

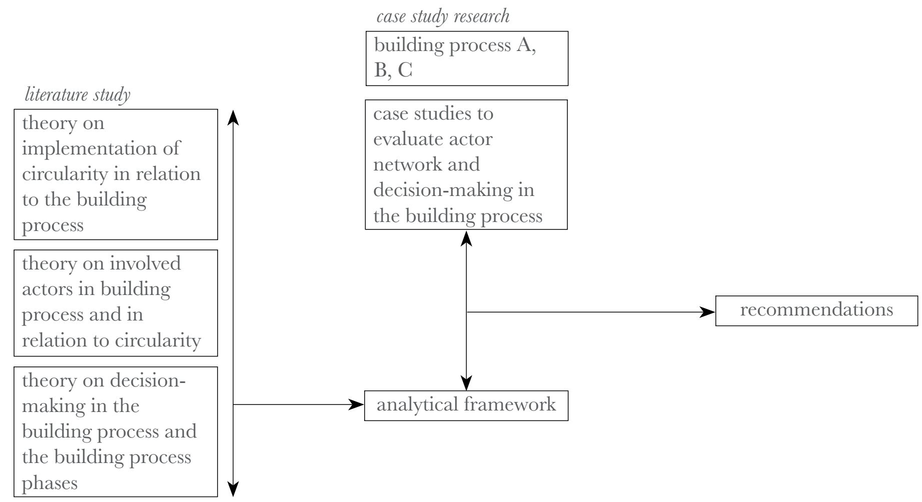
This sub question identifies in which phases of the building process decision-making takes place regarding circularity. The assumption is made the early on decision-making on circularity supports implementation. This sub question aims to find out whether such a particular early on phase can be identified that benefits implementation. This leads to the following hypothesis: *early on decision-making on circularity in the building process benefits its implementation in practice*.

These research questions will be answered by analyzing three recently developed circular building processes using an analytical framework that is based on three strands of academic literature. The conclusions from the analysis then provide recommendations for actors and their influence on decision-making in the building process to facilitate circularity.

1.4 Method

In order to answer the aforementioned research question and sub questions, the research method should facilitate evaluation of current circular projects and making recommendations for an improved situation. Therefore, a combination of theoretical and practical input will be gathered. This is done by means of a literature study, and case studies research including interviews.

As can be seen in Figure 1.7, this method will help to provide context for the analytical framework (literature study), which will provide assessment criteria to evaluate current circular building projects (case studies), by which the case studies can be investigated (relying on data from the interviews), thereby recommendations for improvement can be provided. As can be seen the literature study consists of: theory on implementation of circularity, theory on the involved actors, and theory on decision-making in relation to the building process. From this literature research, assessment criteria for the case study research can be conducted. The case study research is the main method of this research. The case study research will evaluate the actor network and decision-making processes as will follow from three building projects.



A study of recent theories and research reports into the fields of circularity and circular strategies, actor networks, and decision-making processes;

yields criteria on the basis of which the current actor network and decision-making processes of circular building projects are evaluated;

the results of this assessment is processed into recommendations for improving the actor network and decision-making to facilitate circular building projects.

Figure 1.7 Research design.

1.5 Relevance

Several authors indicate the lack of research into practical implementation of circularity to building projects to provide help in the decision-making process – in terms of concrete and workable tools, guidelines, etc. Literature on sustainable and circular strategies to implement circular building processes remains quite theoretical. This thesis aims to provide concrete and practical knowledge to support implementation from the perspective of the actor network and decision-making process in the building process. Thereby, this master thesis provides practical relevance as it aims to deliver recommendations on implementing circularity in the building process.

1.6 Structure of report

This master thesis continues as follows. First, some theoretical background on general concepts regarding circularity is provided. The report then continues with the analytical framework, which is based on a descriptive and reflective literature study on circularity with respect to implementation of circularity, the building process, and actors and decision-making. Subsequently, the method for the case study research is discussed. Next, a short description of the cases is provided. This is followed by the case study research, including analysis of the actor network and decision-making process. What follows is a discussion on the literature and case study results. The report ends by presenting an answer to the sub questions and answer to the main research question in the conclusion section. Then, the results from the case study research and knowledge gathered from the literature study are used to provide recommendations for an improved building process. This is accompanied by recommendations with respect to future research on this topic.

Notes

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). *Circular economy in construction: current awareness, challenges and enablers.* Waste and Resource Management, 170(1), 15–24. https://doi.org/10.1680/jwarm.16.00011

Centraal Bureau voor de Statistiek. (2009). *Milieurekeningen 2008.* Den Haag.

Crowther, P. (1999). *Design for disassembly.* Environmental Design Guide, November. https://doi.org/10.1115/1.2991134

Durmisevic, E. (2010). *Green design and assembly of buildings and systems: Design for disassembly a key to life cycle design of buildings and building products.* Saarbrücken: VDM.

Gerding, D. P. (2018). *Design for Disassembly: a way to minimize building waste (part I).* Delft University of Technology.

Gorgolewski, M., & Ergun, D. (2013). *Closed-loop materials systems.* In Sustainable Building Conference (pp. 235–243). Coventry: Coventry University.

Mcdonough, W., & Braungart, M. (2009). *Cradle to cradle: remaking the way we make things.* London: Vintage Books.

Mulhall, D., & Braungart, M. (2010). *Cradle to cradle criteria for the built environment.* Nunspeet: Duurzaam Gebouwd.

Rau, T., & Oberhuber, S. (2016). *Material matters: het alternatief voor onze roofbouwmaatschappij.* Amsterdam: Bertram & De Leeuw Uitgevers B.V.

2. Theoretical background

This section provides background to some fundamental concepts which are relevant to this thesis. The following concepts will be elaborated on: circularity, including circularity in relation to sustainability; and the built environment, including layers, design for disassembly and the phases of the building process.

2.1 Circularity

One could determine that there has been consensus about the need to deal more sustainably with the environment and its resources. The means to do so, however, are subject to discussion. The current popular 'way to go' is termed circularity, or circular economy. The past years, the term 'circular economy' emerged in the academic and commercial world. The definition of circularity or circular economy is, however, still subject to discussion. A wide range of (different) definitions have been provided by academics, organizations, and governments. In order to provide an understanding of the concept circularity, some definitions will be discussed to come to general characteristics.

Schouten (2016) discusses the concept of circular economy and provides several definitions. Based on the Ellen Mac Arthur Foundation the following definition is provided:

"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." (Ellen MacArthur Foundation, 2012, p.7)

The Dutch Ministry of Infrastructure and the Environment provides the following definition:

"An economic system that takes the reusability of products and raw materials and the conservation of natural resources as the starting point and strives for value creation in every link of the system." (Ministry of Infrastructure and the Environment, 2014, p.1)

Schouten (2016) adds to these definitions that the circular economy should establish decoupling between commercial profit and material and resource use. In other words, the one should not exclude the other. Thus, the objective of decoupling helps to secure economic growth, on the one hand, and sustainable resource consumption, on the other hand (Ness & Xing, 2017). Thereby, the circular economy can be seen as a concept that deals with resource and material use, directed by the need to tackle resource scarcity and the polluting influence of resource extraction and processing.

Geissdoerfer, Savaget, Bocken & Hultink (2017) define circular economy, based on different contributions by other authors as:

"A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." (Geissdoerfer et al., 2017, p.759)

The concept 'circular economy' criticizes the relation between the economy and natural resources. Currently, the production and consumption of goods and products presses the environment and its resources. This system can be characterized as a process of 'take, make, waste' (Geissdoerfer et al., 2017). The end of this process – waste – results in valueless materials and pollution. This linear process should be transformed into a circular process. The idea of a closed loop ascertains use of materials and energy through several loops (or use phases) since their value is preserved (Geissdoerfer et al., 2017).

Bocken, de Pauw, Bakker & van der Grinten (2016, p.309) also include *"slowing, closing, and narrowing resource loops"* in their definition. Within this context slowing down focusses on extending the life time of products, components or buildings; closing focuses on closing resource loops by aligning post-use and production; and narrowing focusses on using fewer material for products, components, or buildings (Lüdeke-Freund, Gold, & Bocken, 2018).

Based on these definitions certain characteristics can be identified. These are depicted in Table 2.1. The last characteristic concerns the multiple value creation aspect. This means that circular economy covers multiple perspective: materials, energy, health, biodiversity, well-being, and labor, amongst others. For the sake of the scope of this thesis, the focus is (only) on materials. In this study the terms 'circular economy' and 'circularity' are used interchangeably.

Table 2.1 Common characteristics of the concept of 'circular economy' based on several definitions.

Circular economy aims to: • Minimize waste and reduces resource consumption; • Keep materials at a high value; • Eliminate the 'end of life' phase by aiming at closed resource loops; • Focus on renewability (Luscuere, 2018); • Cover multiple perspectives: materials, energy, health, biodiversity, well-being, labor, etc. (multiple value creation).

2.1.1 Sustainability

The term circular economy (or circularity) aims to provide economic incentives to deal more consciously with resources, waste and leakage. Within the context of sustainability, several authors define circularity as a precondition or an important aspect for sustainable development. Thereby, sustainability is considered as a broader concept than circularity, the latter generally (only) focuses on resource (or material) input and waste output (Geissdoerfer et al., 2017). Ness & Xing (2017, p.573) position circular economy in relation to sustainability as a way to *"obtain more value from resources while reducing material throughput"*. Other authors also perceive circularity as a means to arrive at sustainable development (Kraaijenhagen, van Oppen, & Bocken, 2018).

With respect to this, literature often displays the picture taken by Frank Borman from the Apollo 8 spacecraft, see Figure 2.1. This picture, called Earthrise, showed – for the first time – the vulnerable and finite entity of the earth. The concept 'circular economy' promises an integral way to deal with the finite earth's resources.

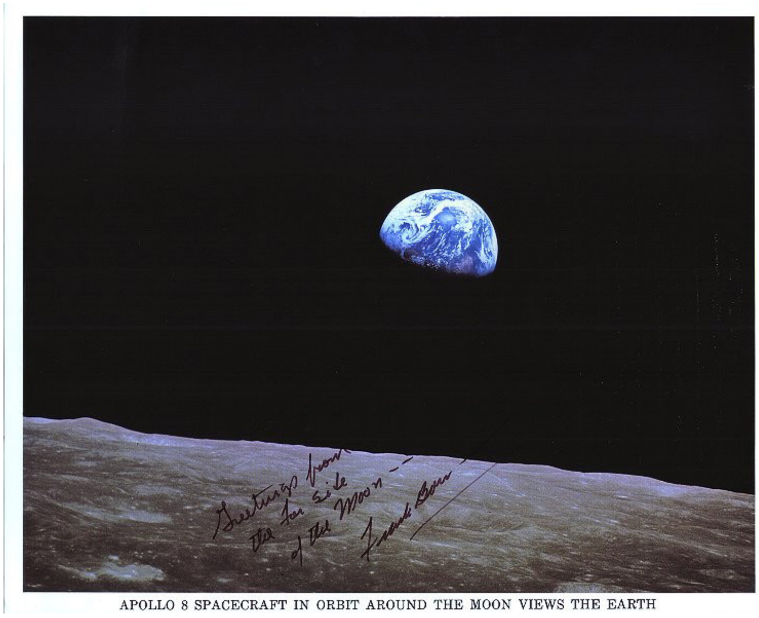


Figure 2.1 Earthrise, the earth as a small element in the universe with only a limited reserve of resources and materials, picture by Frank Borman, 1968. The most influential 'environment' picture of all times (Schouten, 2016).

2.2 Built environment

De Ridder (2018) illustrates that the building sector generates about 45% of the total waste in the Netherlands, whereas it only contributes for 10% to the GNP. This demonstrates the relevance to reduce waste and deal responsibly with materials and resources. According to de Ridder (2018) the skewed relationship that this figure shows, can be explained by the nature of the building process and the building itself. For instance, a building is custom-designed and a building process includes multiple manufacturers (de Ridder, 2018; Kibert, 2013).

The past years, circularity has become a popular term in the built environment. This approach prefers a more circular way of perceiving the building process. By closing 'material cycles' this approach aims to deal more consciously with resources and materials and generally utilizes waste (that is generated after demolition) as a resource (Rau & Oberhuber, 2016; Mcdonough & Braungart, 2009). Thus far, practical implementation of circular economy in the built environment has been limited. Until now, research has mainly focused on recycling and to a lesser extent on reuse (Adams, Osmani, Thorpe, & Thornback, 2017).

The work of Mcdonough & Braungart (2009) elucidates how to deal with resources or nutrients in a durable manner, and at the same time, provide a healthy living environment. Their cradle to cradle philosophy provides a contribution to designing industrial products and consumer goods (and buildings) so as to deliver a healthy, durable and sustainable product (Mcdonough & Braungart, 2009). An important (first) step in their philosophy is to distinguish between technical (man-made) and biological ('natural') nutrients, that each should circulate in their technical or biological cycle.

According to Pomponi & Moncaster (2017, p.711) a circular building is *"a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles"*. This definition shows that for a circular building the whole life cycle should be taken into account. This is also argued by Leising, Quist & Bocken (2018). Their definition of a circular building entails the following: *"a lifecycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank"* (Leising et al., 2018, p.977).

2.2.1 Layers

The above-provided definitions include the concept of a building's useful lifetime. Regarding this concept a short discussion on the notion of layers is relevant. Based on the work of Brand (1994), a building can be classified according to several layers, see Figure 2.2. Each layer – site, structure, skin, services, space plan, stuff – comprises of materials or parts with the same speed regarding maintenance and life time duration. This results in a hierarchy of layers based on time. Crowther (2001) investigated the different *average* lifetime durations of a building's layers, see Table 2.2.

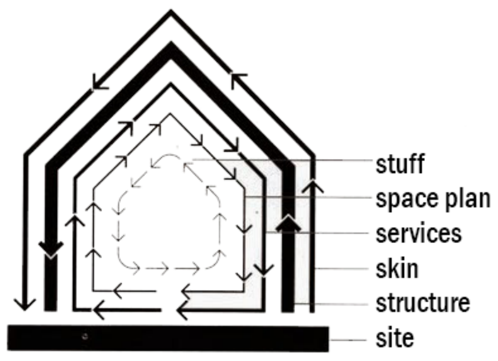


Figure 2.2 Layer model (Brand, 1994).

Table 2.2 Layers of change as identified by Brand (1994) and average life times as determined by Crowther (2001).

Layer	Average life time (years)
site	eternal
structure	50
skin	25
services	15
space plan	10
stuff	1-5

It must be noted that, thus far, the implementation of circularity has mainly been demonstrated for industrial products and consumer goods. Circular strategies (for instance 'product as a service') to support reuse of building components have been (only) in place for building components – and industrials and consumer products – with a relative short life time, such as furniture and lighting (Pomponi & Moncaster, 2017; Rau & Oberhuber, 2016; Ness & Xing, 2017). Bocken, Short, Rana & Evans (2013) show the widespread applicability of circular strategies to the industrial sector, sectors such as furniture, printing, food, and footwear applied sustainability or circularity in their organizations.

The applicability to a building and especially its long-lived layers is still questionable to some extent (Adams et al., 2017). The implementation of circularity in relation to longer life time components (such as the structure and facade) has not been dealt with recently (Adams, Osmani, Thorpe, & Thornback, 2017). Some circular strategies have been applied to the short-lived layers of a building, but the (direct) translation of these applications to the long-lived layers is questionable (Pomponi & Moncaster, 2017). This will be elaborated on further and investigated in section 3. Analytical framework and section 6. Findings.

2.2.2 Design for disassembly

The previous research (part I) focused on the concept 'design for disassembly'. As already elucidated, design for disassembly is defined by the previous research as designing a building in such a way as to *"anticipate the temporality of a building by means of designing a building to be demountable, to be able to reuse or recycle parts and materials, thereby reducing the need for raw materials and minimizing the generation of waste"* (Gerding, 2018, p.56).

In relation to the circular economy, design for disassembly should be applied to maintain a high material value throughout different life cycles, by means of reuse (or recycling) it aims to slow down resource loops (Ness & Xing, 2017). In other words, the life time of building components should be lengthened. Several authors indicate that circular strategies could enable processes to preserve a high value of building components. Leising et al. (2018) state that new types of circular strategies could support supply chain collaboration to close and slow down resource loops.

As will be demonstrated in section 3. Analytical framework, design for disassembly is considered a design strategy. It helps to prepare for reuse or recycling of used components at the end of a building's life time, thereby it focuses on retaining value at the component and material level. It does so by designing the building to be demountable, see also Figure 2.3.

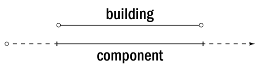
'design for disassembly'
an example of a 'design strategy'

→

focused on **'retaining component & material value'** a 'value retaining strategy'

↓

part of the 'design strategy'
'design for component life extension'



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applicable 'patterns':
1) **'repair & maintenance'**
2) **'reuse & redistribution'**
3) **'refurbishment & remanufacturing'**
4) **'recycling'**

→

the following circular business model strategies (CBMSs) apply:
1) **'functionality without ownership'**
2) **'extending product value'**
3) **'classic long-life model'**
4) **'encourage sufficiency'**
5) **'extending resource value'**
6) **'industrial symbiosis'**

↓

these patterns are aimed at the following 'resource saving strategy':
1) **'closing'**
2) **'slowing down'**
~~3) **'narrowing'**~~

Figure 2.3 The position of 'design for disassembly' within the context of circularity and based on literature and research on circularity. This is based on Lüdeke-Freund et al. (2018); Kraaijenhagen et al. (2018); Ritala, Huotari, Bocken, Albareda, & Puumalainen (2018).

2.2.3 Phases in the building process

Traditionally, the building process consists of several phases. These phases are generally appointed as initiate, prepare, design, build, finance, maintain, and operate (den Heijer & van der Voordt, 2004). Normally the building process follows these phases in this order. As concluded by many researchers, the start of a building process offers room for changing and adapting the project and process and make impact (Wamelink, 2010; van Doorn, 2004). Later on in the building process, this will become more and more difficult, the cost for changes increases and the influence to make changes reduces, see Figure 2.4 (van Doorn, 2004).

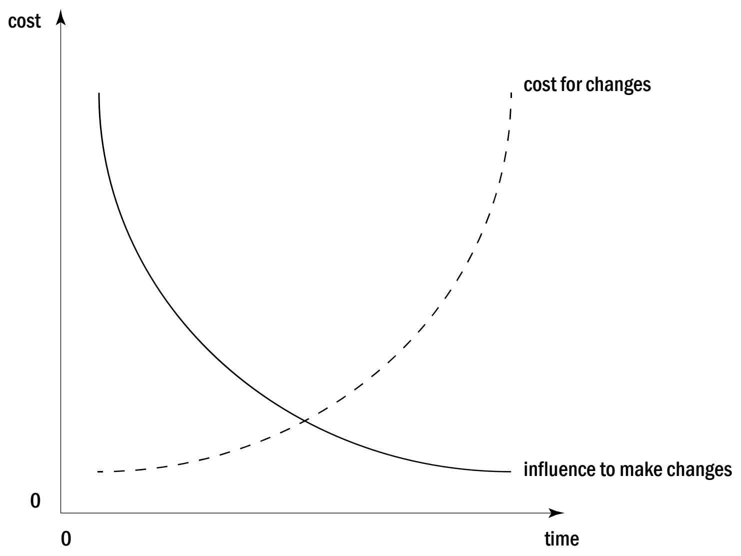

Figure 2.4 Influence on and cost to change in the building process, based on van Doorn (2004); Wamelink (2010); and Kibert (2013).

As argued in the introduction (section 1. Introduction) and as indicated by the previous research (part I), it seems that the beginning of the building process, is an important moment in time to aid implementation of circularity. Especially, the initiation and preparation phase offer room for steering towards circularity. In the conventional building process, these phases include the initiation of the project by the client, owner, or user to build, renovate, or transform a building (or *not* build a new building). Additionally, a rough program of requirements is developed, feasibility studies are conducted, and first designs (sketches) are made (den Heijer & van der Voordt, 2004).

In relation to the conventional building process, one could perceive that decisions regarding implementation of circularity should ideally take place in the initiation and (mainly) during the preparation phase. This moment prepares for and makes possible certain choices at the beginning and end of a building's life time. The preparation phase is the phase where changes can be made to design and construct a demountable building, define reuse and recycling of the components, and conclude agreements on who facilitates reuse and recycling at the end of a building's life time.

The above explanation shows that during the pre-phase preparations for the post-phase can be made to facilitate circularity. In addition, during the pre-phase decisions can be made regarding input of secondhand components (i.e. use of reused components from another building or location). The pre-phase is located at the start of a building's life time and the post-phase is located at the end of a building's life time (when the building is considered obsolete), see Figure 2.5. Figure 2.5 depicts the life time of a building in relation to the life time of two building components. The component's life time could transcend the building's life time. In addition, Figure 2.5 depicts the building process in relation to the building's life time. As can be seen, the initiation, preparation, and design phase offer room for preparing the beginning and end of life scenarios.

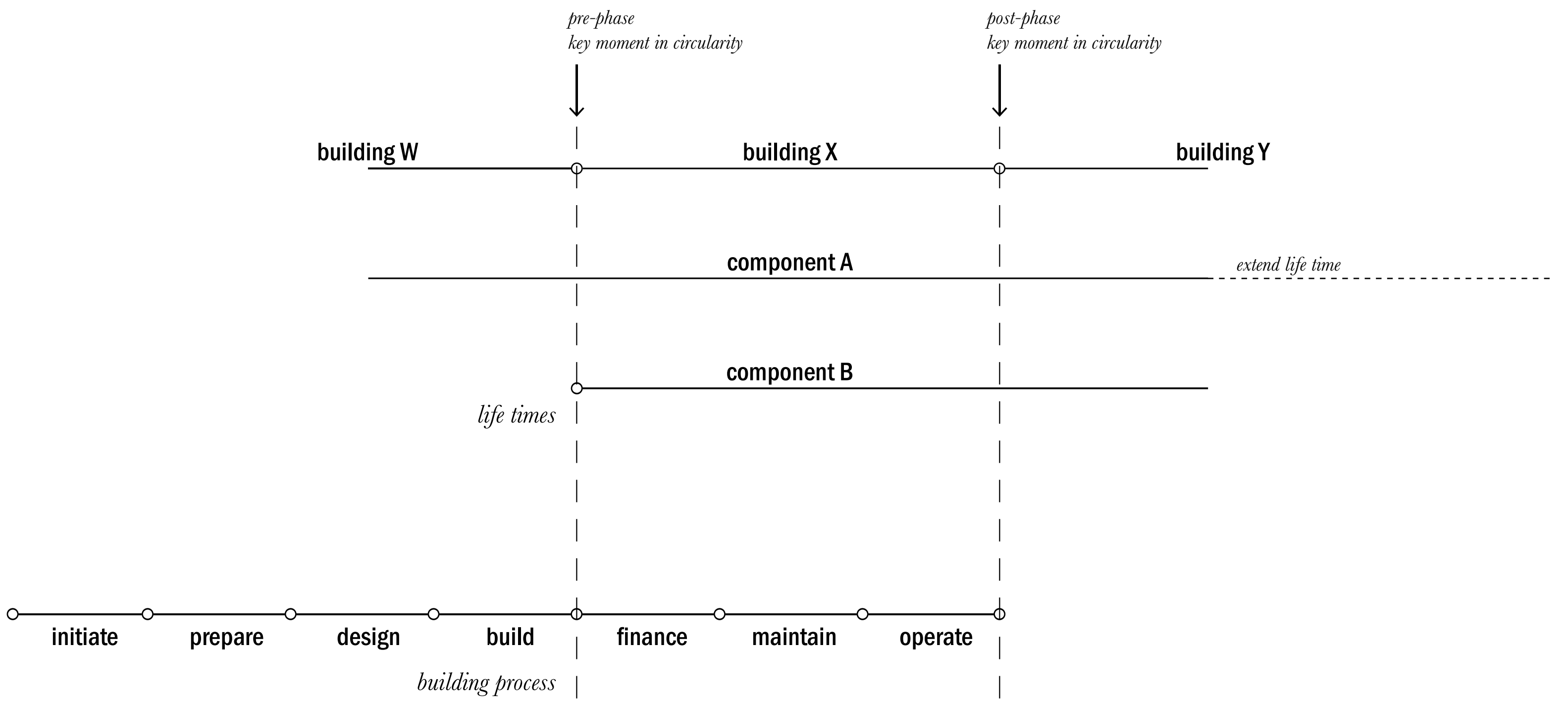

Figure 2.5 A building's life time and building component's life time. Generally, these life times do not match. The building component's life time, for instance, exceeds the building's life time. The component's life should become circular.

Currently, at the end of life buildings are usually (partly) demolished. This end of life stage typically includes two stages in the demolition process. These are: 1) stripping of reusable components, and 2) demolition of the remaining components and materials (Durmisevic, 2010). As explained, the post-phase should instead be focused on reuse of the used components. During the post-phase the building should be disassembled properly, so that its components can be reused (or recycled). To do so, this process would benefit if proper preparations are made already in the pre-phase.

Notes

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3. Analytical framework

This section provides an overview of literature on implementation of circularity and its relation with the phases of the building process. In addition, literature is provided on the actor network with respect to circularity. In order to provide this information, this section relies on literature study research. The current body of literature, in relation to the building process to build sustainable buildings, mainly discusses circular economy and (theoretical concepts on) circular building. Thus far, no clear-cut information on the execution of the building process with respect to *circular building* has been provided. Therefore, information – from circularity related literature – is extracted that is considered relevant, this is based on judgements by the author with respect to her knowledge as developed from the previous research (part I). Preferably, the gaps in this information can be filled up by use of practical knowledge that is gathered from the case study research.

3.1 Implementation of circularity in the built environment

Unfortunately, implementation of circularity is lingering, due to several reasons – of which the fear of transforming the system as a whole is one (Stahel, 2016). In order to facilitate implementation, several authors have developed strategies for implementation. Thus far, theories on strategies for implementation of circularity have only been applied to industrial products and consumer goods. More specifically, within the industrial products and consumer goods sector, circularity has mainly been applied to their organizations and production and manufacturing processes. The application of these theories and strategies to buildings is limited to certain layers, (space plan and stuff layer). Although, literature does provide a range of solutions, these seem to be in its infancy and have not yet fully materialized. Therefore, this section provides an overview of circular strategies and gives a description of these strategies. To do so, a framework is proposed outlining how circularity can be implemented in relation to buildings. It must be noted however, that applicability of the proposed framework to buildings is not ascertained, notes are provided to highlight these uncertainties. Additionally, there is no agreement on how to categorize and position circular strategies. In literature different words are used interchangeably. For instance, 'circular business model', 'circular strategy' and 'circular pattern' are used differently and interchangeably.

This section aims to provide a more logical understanding of circular strategies, its implementation, and relations to other circular-related concepts. It must be noted that time is also an important aspect for circular strategies. In the sense that implementation of circular strategies can focus on the beginning of the building's life time or on the end of the building's life time, and preferably both.

3.1.1 Circular patterns

At the end of a component's life time – this occurs when the component is determined technically, functionally, or economically obsolete – choices can be made regarding its second life and regarding how to deal with waste (Gerding, 2018). Although these decisions determine the *end of life* scenarios, these choices can be prepared for at the *start* of the building process.

Several authors propose a hierarchy of these decisions. The Ladder by Lansink, for instance, provides the following hierarchy: 1) prevent, 2) reuse, and 3) recycle (Lansink, 1979; Schouten, 2016). Mcdonough & Braungart (2009) add 'decompose' to this list, in case of biodegradable components and materials. Peng, Scorpio, & Kibert (1997) provide the following order: 1) reduce, 2) reuse, 3) recycle, 4) compost, 5) incinerate, and 6) landfill. Stahel (2016) concludes that circular strategies can be divided into two categories. The first are strategies that aim for *reuse* (extend service life), the second are strategies that facilitate *recycling* (Stahel, 2016).

Although authors use different words and slightly different categorizations, there seems to be agreement that 'prevention and reduction' is the main aim for dealing with waste, followed by 'reuse', and 'recycling'. Based on Lüdeke-Freund, Gold & Bocken (2018); Kraaijenhagen et al. (2018); Bocken, Short, Rana & Evans (2014); and Ritala, Huotari, Bocken, Albareda & Puumalainen (2018), the following categorization and hierarchy is used for this study to guide beginning and end of life decisions, see Table 3.1.

Table 3.1 Ends and patterns, these serve to arrange priorities for beginning and end of life scenarios.

End	Reduce	Reuse	Recycle
Pattern	1) Prevention & reduction	2) Reuse & redistribution 3) Repair & maintenance 4) Refurbishment & remanufacturing	5) Recycling 6) Cascading & repurposing 7) Organic feedstock

The framework established by Lüdeke-Freund et al. (2018) provides a good starting point to develop a framework for categorizing circular strategies. Lüdeke-Freund et al. (2018) published a paper in which they provide a framework for 'circular economy business model patterns' to support closing resource loops. The work by Lüdeke-Freund et al. (2018) is the basis for the framework, see Table 3.3, which is further enhanced and adapted. As can be seen in Table 3.1, pattern 1 relates to reduce, patterns 2 up to 4 relate to reuse, and patterns 5 up to 7 relate to recycle. These patterns could offer a frame for identifying and positioning circular strategies, and will be elaborated on below.

Prevention & reduction

This pattern is not part of the framework provided by Lüdeke-Freund et al. (2018). Based on the body of literature in the field of circularity and sustainability, this pattern is added (Schouten, 2016; Kraaijenhagen et al., 2018). Prevention and reduction is perceived as the preferred aim for dealing with waste (Lansink, 1979). Preventing and reducing waste and material use can be done by evaluating the need for a (new) building, using less materials, using lightweight materials, and obtaining efficient construction and manufacturing processes (Lüdeke-Freund et al., 2018).

Repair & maintenance

Reuse, as defined by Ness & Xing (2017), extends the life time of the building component. The building component can be, at the building's end-of-life, reused in another building. It could be that this requires maintenance during use of the building component in a certain building constellation, but preferably reuse requires no processing. Ideally, at the end of life the components can be reused, in its current form or in another building (Gorgolewski, 2008). Thus, reuse realizes recirculation of components, while components preserve the same function (Iacovidou & Purnell, 2016). It must be noted that reuse of the building as a whole is preferred, since this *prevents and reduces* materials, waste, and transportation.

This pattern aims to extend the component's life time by repairing deficits and maintaining the condition of the component. Additional services need to be in place to execute this pattern, such as: checking and monitoring the condition, executing maintenance, and carrying out repairs. If the component and building is designed to be disassembled maintenance and repair is eased (Lüdeke-Freund et al., 2018).

Reuse & redistribution

The reuse process sometimes requires redistribution, if on-site reuse cannot be established. In case of off-site reuse the market value of the component needs to be determined, trade takes place on a market place, and then the component needs to be transported and stored, and sometimes repairs or modifications need to be made (Lüdeke-Freund et al., 2018). The process is facilitated if the design is flexible, since reclaimed components are often not readily available or their specifications are not perfectly suitable (Gorgolewski, 2008). Gorgolewski (2008) notes that, because of these reasons, reuse could impede greater implications on the building design than recycling.

Although this study focuses on reuse at the level of the building component, in some cases reuse of an existing structure seems eligible (Kibert, 2013). In case of a renovation project, reuse of the existing structure could be favored over reuse of the individual components, the first requires less energy in terms of transportation, for instance. The building, however, should be designed to be deconstructed – so that its components can easily be reused in the end.

Refurbishment & remanufacturing

This pattern is a combination of 'repair & maintenance' and 'reuse & redistribution'. The refurbishment & remanufacturing pattern is also aimed at reuse, but requires refurbishment or remanufacturing to offer a component with a proper condition. In other words, the component need to be upgraded to provide an appropriate physical condition (Lüdeke-Freund et al., 2018).

Regarding the process of refurbishment & remanufacturing, this requires take-back to the supplier, or another third-party actor that could execute the upgrading. This actor should also have the authority to provide a warranty or certificate of performance. Thus, transport, dismantling, cleaning, testing, repairing, storing, and meeting demand and supply are essential for this pattern. It must be noted that the additional energy for refurbishment and remanufacturing must be in proportion to the life time of the component (Lüdeke-Freund et al., 2018).

Recycling

Recycling requires processing of components into materials and subsequently into new components (Iacovidou & Purnell, 2016). After recycling, components could obtain a different than their original function. In this respect the term downcycling is used for components that degrade in function after recycling. And upgrading is used for components that upgrade in function after recycling (Lüdeke-Freund et al., 2018; Adams, Osmani, Thorpe, & Thornback, 2017). For instance, a concrete column that is recycled into concrete flooring is a form of downcycling, since this new function demands lower strength capacities. Bocken, de Pauw, Bakker & van der Grinten (2016) argue that recycling occurs, because of inefficiencies in current linear processes. In other words, high- or same-value reuse of these components is not possible, because of their linear production and use, resulting in waste at the end.

The recycling process requires: sourcing for waste materials, transport back to the supplier or another third-party actor capable of recycling (this could be incentivized by means of a deposit), separation, and processing (Lüdeke-Freund et al., 2018). As the case for reuse, the energy required for recycling must be taken into account (Lüdeke-Freund et al., 2018).

Cascading & repurposing

This pattern, aimed at recycling, reprocesses components into materials and then into new components. In comparison to the previously described pattern, this pattern actively uses waste as input. More specifically, the input consists of components or products that do not necessarily originate from the built environment (Lüdeke-Freund et al., 2018). Thus, cascading and repurposing could entail components from other sectors, for instance clothing or industrial products, that can be recycled into building components (Mcdonough & Braungart, 2009). According to Lüdeke-Freund et al. (2018) this pattern is mostly applied to biological nutrients, but could also be applied to technical nutrients. It must be noted that this process is most suitable for short-lived layers, such as stuff and space plan (for instance, wasted jeans used as insulation or fishnets used as carpet), since it is unlikely that these kind of recycled products will provide structural and technical capacities required for the structure and skin.

The recycling process requires: collection of suitable components and products, separation into biological and technical nutrients, transport back to an actor capable of recycling (Lüdeke-Freund et al., 2018). This process requires relationships with actors from sectors other than the building environment to find suitable waste components and products.

Organic feedstock

This pattern provides an end of life scenario for biological nutrients. It processes biological nutrients via biomass conversion and composting (Lüdeke-Freund et al., 2018). According to Mcdonough & Braungart (2009) for biological nutrients the resource loop can be closed by means of decomposition, their 'cradle to cradle' principles link to this pattern. For this pattern to work, ideally, biological and technical nutrients should be separated (Mcdonough & Braungart, 2009). This processes requires: separation of biological nutrients, collection of biological nutrients, transport, and processing (Lüdeke-Freund et al., 2018)

3.1.2 Resource strategy

The above described patterns each aim to deal more consciously with waste and materials, and in that way potentially have an effect on resource use. Thereby these patterns contribute to obtaining a closed resource loop. Ideally these resource loops should be closed, so that no waste remains at the 'end of life'. Based on the work of Stahel (2016), Mcdonough & Braungart (2009), and Bocken et al. (2016) resource loops could be narrowed, slowed down, or closed. Each pattern relates to these different resource strategies, see also Table 3.3. The 'prevention & reduction' pattern aims to narrow resource loops. Narrowing means *"using fewer resources per component"* (Kraaijenhagen et al., 2018, p.29). The following patterns aim to slow down resource loops: 'repair & maintenance', 'reuse & redistribution', and 'refurbishment & remanufacturing'. Slowing down means *"extending the use period of a component"* (Kraaijenhagen et al., 2018, p.29). 'Recycling', 'cascading & repurposing', and 'organic feedstock' aim to close resource loops. Closing means aligning *"post-use and production"*, in other words aligning the end and beginning of life (Kraaijenhagen et al., 2018, p.29).

In order to prevent waste at the end of a building component's life, ideally, one should aim for a closed-loop life cycle. As similar to nature, where at the end of life, materials *decompose* (Addis, 2006). Mcdonough & Braungart (2009) argue that for materials that are part of the biological cycle (biological nutrients) decomposition happens at the end of life. For technical nutrients, however, 'reuse' or 'recycling' are means to close the loop. It must be kept in mind, as explained, that before considering reuse or recycling, prevention and reduction should be considered (Schouten, 2016).

3.1.3 Value strategy

In addition to these resource strategies, the patterns relate to certain value strategies. These value strategies relate to the level at which the pattern is focused. Circularity aims to retain value or even create value and value degradation (as is the case for downcycling) should be prevented. According to Lüdeke-Freund et al. (2018) patterns should either retain *product* or *material* value. With respect to the built environment, this would be aimed at retaining value at the component or material (or building) level. Patterns that utilize slowing down as the resource strategy retain *component* value, whereas strategies aimed at closing down resource loops retain *material* value. Narrowing resource loops relates to both the *component* and *material* level.

3.1.4 Circular strategies

Several authors have defined circular strategies (CSs). A CS relates to the way business is done, or with respect to circular building how circularity could be implemented. In relation to waste, some strategies are focused on dealing with waste at the end of life, others are focused on preventing waste upfront (Addis, 2006). Thus, these strategies can be applied as a beginning or end of life scenario. The start of the building process provides an important moment to prepare for beginning and end of life scenarios and make preparations for closing, slowing down or narrowing resource (and material) loops.

Ritala et al. (2018) and Kraaijenhagen et al. (2018) provide a categorization of sustainable or circular strategies. This thesis builds upon their categorization of CSs. These CSs are categorized in Table 3.2. It must be noted that multiple circular strategies could be utilized to facilitate implementation of circular building (Kraaijenhagen et al., 2018). These CSs will be elaborated on below.

Table 3.2 Categorization of circular strategies.

To narrow:
- Maximize material/resource and energy efficiency
- De-materialization

To slow down:
- Functionality without ownership: product service system (PSS)
- Extending product value
- Classic long life model
- Encourage sufficiency

To close:
- Extending resource value
- Industrial symbiosis

To narrow: Maximize material and energy efficiency, de-materialization

'Maximizing material and energy efficiency' and 'de-materialization' focuses on preventing waste. This results in doing more with less or using less materials and fewer resources. This means that dealing with resources and materials should be done effectively and efficiently (Kraaijenhagen et al., 2018). In relation to buildings, these CSs could implicate that instead of building a new building, an existing building structure is used. This prevents construction of a new building structure with 'new' materials. Additionally, these CSs could also implicate that a building's structure or facade is designed more efficiently in terms of material use. In other words, the grid or dimensions could be adjusted so that less materials are utilized (Lüdeke-Freund et al., 2018).

To slow down: functionality without ownership: product service system (PSS), extending product value, classic long life model, encourage sufficiency

These CSs slow down resource loops by extending the life time of components or the building itself. Extending the life time is done by means of proper maintenance and repair or redistribution (Kraaijenhagen et al., 2018). Thereby these CSs facilitate reuse. In addition, reuse could require refurbishment and remanufacturing (Lüdeke-Freund et al., 2018).

Functionality without ownership is the most-applied CS. This strategy, also known as a product service system, is aimed at providing a service instead of a physical product or component (Kraaijenhagen et al., 2018). Product service systems have been extensively described and reviewed by Tukker (2015). Tukker (2015, p.76) defines a product service system as *"a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final consumer needs"*. This service can be offered to or co-produced with consumers. This strategy is based on the principle that a product-oriented business is likely to increase the number of products sold, and thereby the materials used, whereas a service-oriented business would lower material use to provide services that are more profitable for the firm. This provides the following incentives: 1) extend the service life, 2) ensure intensive use, 3) focus on cost- and material-efficiency, 4) re-use as much as possible at the end of the service life (Tukker, 2015).

It must be noted that these incentives that ideally follow from this strategy are not secured in practice. It could be that this strategy, even, potentially intensifies use or leads to less careful use of the components, which would increase maintenance or detriments reuse possibilities. Potentially, this is due to the fact that ownership usually equals more conscious use. *"Consumers simply value owning things and having control"* (Tukker, 2015, p.88). For instance, leasing, renting, sharing, or pooling incentivizes less careful use by customers (Tukker, 2015). Considering these limitations, this strategy probably works best for products or components that are *"expensive, technically advanced, requiring maintenance and repair, easy to transport, used infrequently by customers, and not heavily influenced by branding"* (Tukker, 2015, p.86).

'Extending product (or component) value' is aimed at *"exploiting the residual value of products"* (Kraaijenhagen et al., 2018, p.24). This means that at the end of life the component is reused again in another constellation.

The 'classic long life model' focuses on providing components with a long life time. Durability is thus achieved by the long usage period (Kraaijenhagen et al., 2018). This is different from the extending product (or component) value model in the way the component is designed. Since for this CS the component is designed with a long life time in mind and aims to extend the use period in the *same* constellation.

'Encourage sufficiency' also focuses on extending the life time of components by providing options for repair and maintenance (Kraaijenhagen et al., 2018).

Table 3.3 Framework of circular patterns and their subsequent circular strategies (CSs), resource strategies, value strategies, and design strategies, based on and expanded from Lüdeke-Freund et al. (2018); Kraaijenhagen et al. (2018); Addis (2006); Ritala et al. (2018); and Bocken et al. (2016), these can be applied as a beginning and as an end of life scenario for the building.

Circular strategy (CS)	Maximize material and energy efficiency De-materialization	Functionality without ownership: product service system (PSS) Extending product value Classic long life model Encourage sufficiency			Extending resource value Industrial symbiosis		
Ends	**Reduce**	**Reuse**			**Recycle**		
Patterns / **Design strategies**	Prevention & reduction [1]	Repair & maintenance [2]	Reuse & redistribution [3]	Refurbishment & remanufacturing [4]	Recycling [5]	Cascading & repurposing [6]	Organic feedstock [7]
Design for resource efficiency	x						
Design for long-life components/buildings		x	x	x			
Design for component/ building life extension (i.e. design for disassembly)		x	x	x	x		
Design for technical cycles					x		
Design for biological cycles					x	x	x
Resource strategy *Potential effects on resource use*	Narrowing	Slowing down			Closing		
Value strategy *Potential value-retaining effects*	Reduce component & material input & output	Retain component value			Retain material value		

To close: extending resource value, industrial symbiosis

These CSs – 'extending resource value' and 'industrial symbiosis' – both focus on aligning waste output with input for another component manufacturing processes, thereby closing the resource loop. These CSs use materials or components which are regarded as waste as input. Extending resource value exploits *"the residual value of resources"* (Kraaijenhagen et al., 2018, p.25). Industrial symbiosis uses waste output from one process as input for another process. This process is benefited if these processes occur in geographical proximity (Kraaijenhagen et al., 2018).

3.1.5 Design strategies

Certain design strategies can be identified that relate to the different objectives of reducing, reusing, and recycling. These design strategies can be applied to the building design and help to facilitate and prepare for end of life scenarios. Concerning the scope of this research, design strategies will not be not discussed elaborately. The following design strategies are identified, based on Lüdeke-Freund et al. (2018) and Mcdonough & Braungart (2009):

- Design for resource efficiency: using fewer materials, using less resources, choosing lightweight materials, and choose grid dimensions and component dimensions so as to reduce material.
- Design for long-life components/buildings: design for a long life time building or long life time component, by choosing durable materials with limited need for maintenance.
- Design for component/building life extension: include some degree of flexibility into the design to secure adaptability and upgradability of the building, design connection to be demountable. Design for re- and disassembly can be considered part of this design strategy.
- Design for technical cycles: include (only) technical nutrients in the design and secure separability with other layers or materials. Mulhall & Braungart (2010) position the cradle to cradle philosophy as being both a design strategy and circular strategy. Based on the work by Lüdeke-Freund et al. (2018) cradle to cradle is defined as a design strategy that aims to close resource cycles.
- Design for biological cycles: include (only) biological nutrients in the design and secure separability with other layers or materials. The cradle to cradle philosophy (including the aspect of separating biological and technical nutrients) can be considered as also part of this design strategy.

The different layers of a building

Some authors indicate differences in applicability of the above described strategies for long-lived layers (site, structure, skin) and more short-lived layers (services, space plan, stuff). According to de Ridder (2018) long-lived layers, with a life time that generally transcends the building's life time should be reused. And short-lived layers, with a life time shorter than the building's life time in general, should be recycled with a minimum amount of energy (de Ridder, 2018). This difference between long- and more short-lived layers is also emphasized by Leising, Quist, & Bocken (2018). For short-lived layers *"suppliers can take responsibility [...] via take back schemes"* by means of leasing or buy back guarantee (Leising et al., 2018, p.984). Components and materials with a long-lived lifecycle can be dealt with via market places where demand and supply of secondhand materials is matched (Leising et al., 2018).

3.2 The different phases of the building process and circular aspects

The previous section provided a framework for categorizing circular strategies. Preferably, these strategies should materialize in the building process. Therefore, it is of importance that certain decisions are made over time. For instance, the use of secondhand materials needs to be discussed and 'end-of-life' scenarios need to be considered. This section discusses what topics should be discussed with respect to the previously provided framework. In comparison to the traditional building process and based on the framework (see Table 3.3) some additional aspects should be introduced and included in the decision-making process.

3.2.1 Initiation phase

As already introduced in section 2. Theoretical background, the initiation phase and preparation phase provide important moments in time for implementing circularity. In the initiation phase the decision to build (or not to build) is made (den Heijer & van der Voordt, 2004). As clearly follows from the framework (Table 3.3), before arriving at such a decision the different 'ends' (reduce, reuse, recycle), should be considered. Since it is likely that after considering these scenarios, it could be that case that *not* building a new building (reduction) is preferred. At last, this scenario should be considered.

3.2.2 Preparation phase

The preparation phase includes several preparatory activities, such as defining the program of requirements and conducting feasibility studies. In addition, development of a (rough) design is started (den Heijer & van der Voordt, 2004). With respect to the previously provided patterns and accompanying CSs and design strategies, it is argued that decisions should be made concerning additional circular-related activities. In comparison to the traditional building process, it can be argued that some additional activities need to take place or additional topics need to be discussed during the building process. These mainly relate to the beginning and end of life scenarios of the building, such as: deciding on storage facilities for reused materials, deciding on what type of materials to acquire, deciding on how to incorporate reused materials in the design, etc.

This is visualized in Figure 3.1. As can be seen, although this study focuses on the 'end and 'beginning' of the building process – or in other words the step from 'remove' to 'design' – proper maintenance and repair during the use phase is also important. Since proper maintenance will secure the building components to maintain good quality and will make it easier to reuse these components at the 'end-of-use' phase. In addition, as can be seen, some activities already take place in the conventional building process, such as transportation of materials to the construction site. Although not all these aspects can be considered as 'new' to the building process, it is important to be aware of the steps that should be undertaken to implement certain patterns.

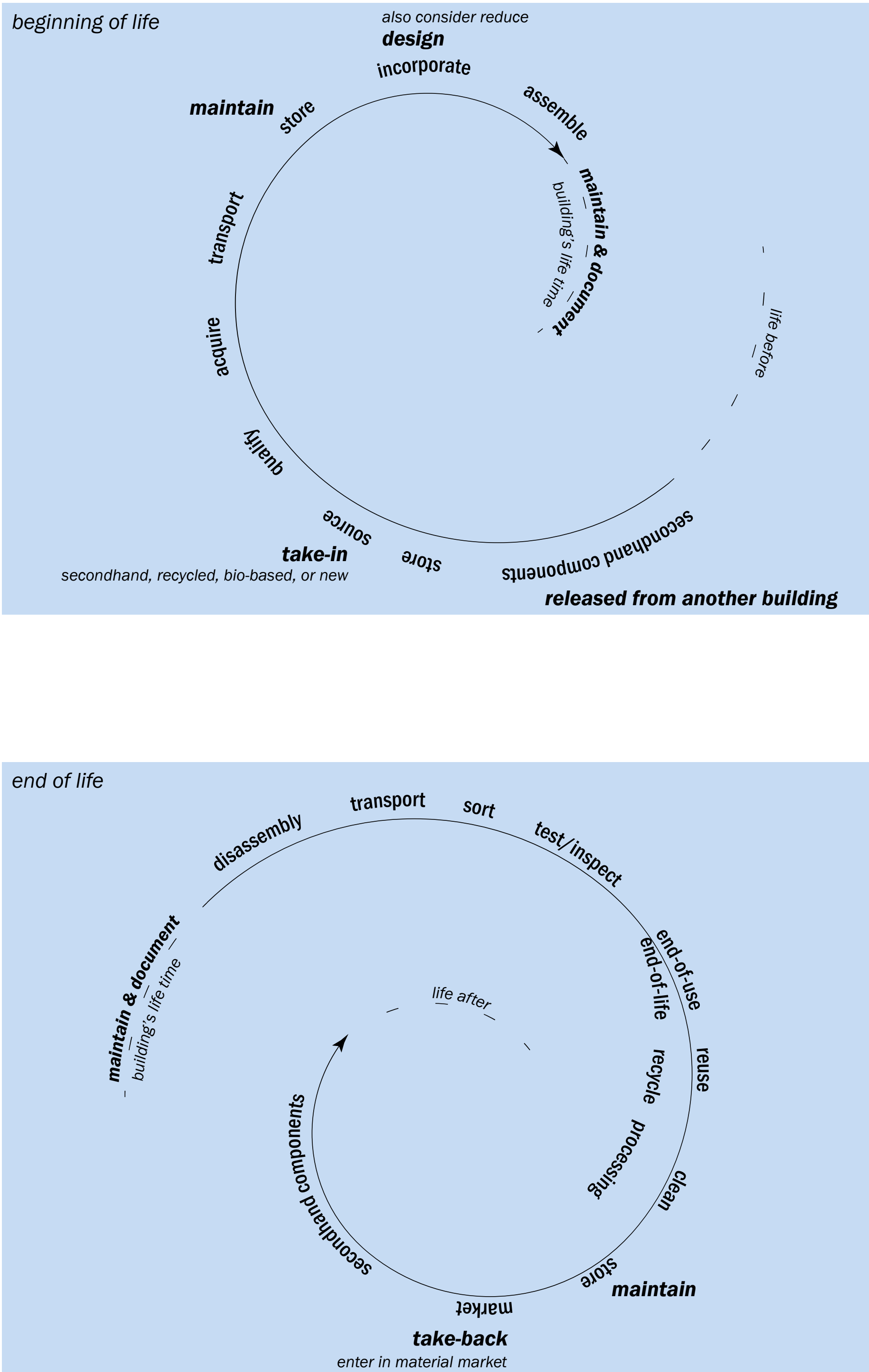

Figure 3.1 Activities at the beginning and end of life of the building to secure use of secondhand components upfront and reuse of secondhand components afterwards.

These steps can be ordered into (more general) categories, see Table 3.4. Based on literature from Adams et al. (2017); Addis (2006); Allwood, Ashby, Gutowski & Worrell (2011); Iacovidou & Purnell (2016); Kibert (2013); Lüdeke-Freund et al. (2018); and Osmani, Price & Glass (2006) the following categorization is provided. It must be noted that this categorization is not clear-cut, some categories overlap. Take-back management, for instance, also requires transport. This overview does not aim to provide separated categories, but merely aims to help to identify important activities that should take place or should be considered in decision-making in the building process. These categories will be elaborated on below.

Table 3.4 Overview of activities per category in relation to component and material processing.

Waste handling & processing	**Transport & logistics**
• Disassemble, deconstruct, dismantle	• Coordination
• Assemble	• Planning
• Modify, processing	• Collect
• off-site / on-site	• Deliver
• outsourcing / in-house	**Acquire & procure**
• site cleaning	• Procure reused & recycled materials
Maintenance & repair	• Sell used materials
• Maintain	• Demand & supply of secondary components
• Repair	• Proximity of demand & supply
• Clean	• Trade
• Test	• Market place/platform
Take-back management	• Harvest map
• Locate	**Information & documentation (provide an identity)**
• Sort	• Availability in markets
• Separate	• Documentation (quality and quantity)
• Classify	• (shared) information
• Store	• Circularity/material passport, BIM
• Certify	• Material inventory
• Warranty, insurance, liability	

Waste handling & processing

This category includes (not necessarily in this order): disassemble, deconstruct, dismantle; assemble; modify, processing, and site cleaning. Other aspects to be discussed or decided upon are whether waste handling and processing takes places on-site or off-site. Additionally, activities can be outsourced or executed in-house, depending on the required expertise. On-site reuse – including careful dismantling, labelling, and modifying – reduces transport. Enough storage space, however, must be available (Gorgolewski, 2008).

Maintain & repair

This category considers the following activities: maintain, repair, clean, and test. This category relates to (re)processing that needs to be done to be able to reuse (or recycle) components (or parts of buildings). In addition, also during a building's life time proper maintenance and repair is important to secure good quality of the components. This could include maintenance, minor improvements, and major renovations (Koutamanis, Reijn van, & Bueren van, 2018).

Take-back management

This category includes aspects such as: sorting; separation; classification; storage; certification; and warranty, insurance and liability. These aspects can be illustrated with an example: *"a steel beam* *may need to be cleaned, cut to length, prepared for new end-connections and corrosion protected. [...] It would then be supplied with a warranty"* (Addis, 2006, p.15). Addis (2006) notes that two periods of storage might be required. One between purchase and refurbishment, and one after refurbishment and before assembling. The value of the component or material is a determining factor when considering the feasibility of take-back management (Peck, 2018).

Transport & logistics

This category includes the following: coordinating, planning, collecting, and delivering. Proper coordination of transport could minimize storage duration and space that is required for components and materials (Kibert, 2013). These transport aspects should be taken into account when assessing the environmental performance of reuse or recycling (Iacovidou & Purnell, 2016).

Acquire & procure

This category includes: procurement of reused and recycled materials, and selling of used materials. This process can be facilitated by means of a marketplace or platform. This marketplace offers a space for trade and helps to match supply and demand. In addition, a harvest map – a tool that maps released secondhand components – could aid in investigating supply of secondhand components. It must be noted that close proximity of demand and supply could accelerate and stimulate reuse of components. Ideally, components should first be sourced and purchased, before the (detailed) design is started (Addis, 2006). Accordingly, before dismantling an existing building, a material audit should be conducted to set up an inventory of materials that are valuable (Kibert, 2013).

Currently, transfer of secondhand components and materials (via marketplaces) is in its infancy. The available quantity and quality (dimensions, volume, etc.) of building components is highly variable and dependent on the deconstruction process of existing buildings. These components lack standardization and dimension coordination (da Rocha & Sattler, 2009). In order to secure implementation of these 'released' components, actors should deal with the availability (and characteristics) of components early on in the building process (da Rocha & Sattler, 2009; Koutamanis et al., 2018).

Information & documentation

This category includes: documentation, sharing information (by means of a circular/material passport, BIM), and setting up a material inventory. Documentation includes documentation of the quality and quantity of components as well as documentation of their availability in markets. According to Iacovidou & Purnell (2016) reuse of secondhand components is limited by uncertainty about the properties of the component or material. Sometimes this is limited by regulations in building codes and standards – secondhand components are not considered as compliant with these rules. The negative perception of secondhand components is also a limiting factor.

For most circular strategies, information and documentation is an important aspect for implementation. Krook & Baas (2013) discuss the importance of documentation and provision of information in relation to urban mining. Addis (2006) states that almost all components and materials can be reused and recycled as long as information is provided and documented regarding their condition and properties. Proper documentation and provision of information could also help to overcome the negative perception, since characteristics of the components are known. Additionally, this information can include agreements on end of life scenarios. For instance, agreements could be made and laid down to return components to a supplier, or to pay a monthly fee for maintenance during the building's life time (van Tuijl, 2018).

3.3 Actor network

The construction of a building is usually executed by a project team. In this project team several actors are involved. These actors are generally from different organizations. This results in an inter-firm network (Bondt de, Drunen van, & Lassche, 1993). This is a temporary collaboration which is created specifically for the building project. It could be, however, that parties already have collaborated in the past (and will collaborate in the future). This interfirm, multi-actor organization can be perceived as a complex *network* of actors (den Heijer & van der Voordt, 2004).

This section provides information on involved actors in the building process and their influence on decision-making. This is perceived from the perspective of circularity. The following topics are discussed: actors and their resources, relations in the actor network, and last their influence on the decision-making.

3.3.1 Actors

It must be noted that the project team constitutes of certain actors. Traditionally these actors are usually the designer, contractor, some specialists (normally a structural engineer and an engineer on building technology), and sometimes also the client (Bondt de et al., 1993; Wamelink, 2010). Typically these actors collaborate intensively and communicate frequently. The actors outside the *direct* project team could also contribute to the project, but on a less intensive and frequent basis. Table 3.5 provides a list of actors who are traditionally involved in the building process. As can be seen, these actors could come from organizations in the public and private sector. Although these actors are formulated in singular form, it could be that multiple actors from certain categories are involved. For instance, normally multiple subcontractors and specialists are involved (Ness & Xing, 2017).

Table 3.5 List of 'traditional' actors based on Wamelink (2010); van Doorn (2004); and Ness & Xing (2017).

The identified actors, which could be from public or private parties, are:

1. Client
2. Program manager
3. Project manager
4. Project developer
5. Contractor
6. Subcontractor
7. Specialist
8. Designer
9. Supplier
10. Renter, user
11. Consultant
12. Government planner, policy maker

According to den Heijer & van der Voordt (2004), the past decades, the building process and actor network has become more complex. This is, amongst others, the consequence of increasing demand and need for specialized knowledge, for sustainable building for instance (den Heijer & van der Voordt, 2004). This has resulted in an increase in consultants and other specialists with specialized knowledge. With respect to this, actors that could offer knowledge on circularity, and therefore could be important to involve, are categorized as follows: circularity expert, dealer in salvaged goods, and reclamation expert. A circularity expert could be a consultant or advisor who provides knowledge and information on circularity (van Doorn, van Bueren, Chao-Duivis, de Jong, & van der Voordt, 2012). A dealer in salvaged goods is able to identify and market construction components that they have identified as valuable (Addis, 2006). The salvaged goods (or components) should be collected and made available for others by means of a market place or another platform (Rau & Oberhuber, 2016). A reclamation expert could inform the project team about where and how materials can be reclaimed (Adams et al., 2017).

According to Adams et al. (2017) important actors in relation to circular building are: contractors, clients, product manufacturers (suppliers), designers, demolition contractors, government representatives, and researchers and consultants. Additionally, some authors argue that the project team should work closely with the building owner and dismantler to implement circularity (Addis, 2006; Adams et al., 2017; Peng et al., 1997; da Rocha & Sattler, 2009; and Gorgolewski & Ergun, 2013). A dismantler could provide experience in dealing with construction and demolition waste, waste processing, and, probably, has knowledge on secondary markets. In addition, Gorgolewski (2008) notes the importance of involvement of a dismantler, since this actor is specialized in deconstructing instead of demolishing a building. Currently, traditional demolishers expand their knowledge and expertise towards deconstruction (Kraaijenhagen et al., 2018).

Kraaijenhagen et al. (2018) indicate a 'transformation agent' as an important actor for implementing circularity. This actor has a central position in the actor network. This actor steers the circular building project and takes the lead in guiding other actors towards the circular goal. The shift towards circularity requires a change in mind, attitude, and behavior (Kraaijenhagen et al., 2018). According to Kraaijenhagen et al. (2018, p.100) implementing circularity requires *"people who can inspire, initiate, support and accelerate this particular circular journey"*. A transformation agent could fulfil this role.

Beside these actors, some *facilitating* actors can be identified. These actors do not provide knowledge or expertise on circularity, but could help to implement circularity in terms of legal (contracts), insurance, and financial requirements. Circularity, often, brings with it new strategies (or new ways of working) which are perceived as increased risk (Bocken, Short, Rana, & Evans, 2013; Kraaijenhagen et al., 2018; Addis, 2006). These actors could help in allocating and mitigating these risks. In addition, a logistic partner could help to take back (by means of transport) (wasted) components to a manufacturer and offer removal of building components at the end of life (Lüdeke-Freund et al., 2018; Kraaijenhagen et al., 2018; da Rocha & Sattler, 2009).

Table 3.6 summarizes these actors that could assist implementation of circularity. Mainly, these circular-related actors could facilitate in making circular decision-making or executing activities as discussed in the previous sections 3.1 and 3.2. It must be noted that these categories are

Table 3.6 List of circular-related actors based on Ness & Xing (2017); Lüdeke-Freund et al. (2018); Addis (2006); and Kraaijenhagen et al. (2018).

Leading actor
1. Transformation agent
Circular specific actors
2. Circularity expert
3. Dismantler
4. Dealer in salvaged goods
5. Reclamation expert
Facilitating actors
6. Logistic partner
7. Financier/risk analyst
8. Insurance company
9. Legal officer
10. Investors

somewhat simplified and could include multiple actors. For instance, a reclamation expert could also indicate an urban miner or a recycling company. Moreover, an actor could fulfill multiple roles, for instance, a supplier could also act as reclamation expert (Lüdeke-Freund et al., 2018). Furthermore, 'traditional actors' could also act as 'circular actors' by obtaining circular expertise. A designer, for example, could source for secondhand materials and thereby act as reclamation expert. Or a contractor could source and purchase secondhand components (Addis, 2006).

Resources

In the above provided description on actors, some resources that these actors possess were already shortly discussed. Each actor contributes to the building process by means of certain resources they possess (Ness & Xing, 2017; den Heijer & van der Voordt, 2004). These resources could be the following: information & knowledge (and skills); instruments (i.e. subsidies); manpower & money (i.e. financial means or workforce); authority (formal power); position in the network (support from or access to other actors); and organization (ability to mobilize and use resources effectively and efficiently) (Enserink et al., 2010).

These categories of resources have general terms. With respect to the circular-related actors these resources are also circular-related. In other words, a circularity expert could provide information & knowledge (and skills) on implementation of circularity, more specifically this actor could offer information & knowledge on choosing a design strategy or aid in considerations regarding CSs.

3.3.2 Relations

Besides the formal established relations (by means of a contract, see also section 3.4 Contextual factors), several informal relations are established that influence decision-making in the building process. For instance, if a client has a relation with a dismantler, it is more likely that decisions will be made regarding agreements on take-back management or dismantling of a building. This relationship could offer a different scenario than the current one, in which the client is responsible for taking actions regarding reuse and recycling of products and materials at the end of life (Stahel, 2016).

Already established relations

Although the project organization itself is temporary, the relationships could be long-term. If actors have collaborated in the past, they are more likely to open up to collaborate and thing along. Besides, these actors know each other well (their strengths, weaknesses, and way of working) which could support collaboration (van der Lingen, 1998). Generally, long-term relations with the (same) actors enable trust (Kraaijenhagen et al., 2018).

3.3.3 Influence on decision-making

Actors involved in the building process work towards the same goal. In other words, there is a common objective to construct a building (or to decide to not build) (den Heijer & van der Voordt, 2004). In this respect, the actors work cooperatively. The building process consists of exchanging ideas, considering different scenarios, and evaluating solutions (den Heijer & van der Voordt, 2004). Another dimension of the building process is of a less cooperative nature. Naturally, each actor has a personal interest in the project (Wamelink, 2010). The decision-making process is a combination of cooperativeness and own interest (Teisman, 2000).

Section 3.3.1 provided a long list of traditionally involved and circular-related actors with respect to the building process. Also, in the previous section, the position of the project team was discussed. The project team has formal influence on the decision-making. This is formally laid down in the form of a contract (see also section 3.4 Contextual factors). Oftentimes, other actors also have influence on the decision-making – be it formally because they are contracted to act as advisor or consultant or informally via informal contact with certain actors. These actors, however, do not have direct influence on the project (as is the case for the project team) but act more *indirectly*. Figure 3.2 provides a visualization of this direct and indirect actor environment. This visualization also provides a distinction between the traditionally involved and circular-related actors. In addition, a stakeholder environment is identified. In the stakeholder environment, actors are positioned who could have a *stake* in the project, but do not exert influence on the decision-making, unless they are invited to join the process. As can be seen in Figure 3.2, the circular-related actors are mainly positioned in the indirect environment. This means that their influence on the decision-making process is limited. It could, however, be the case that their resources could have a positive impact on the building and building process. When implementing circularity, their resources could help to support this process and aid in evaluating circular options. Each actor could influence the decision-making process by means of the resources they possess – this is what they could offer. Within the actor network several subgroups can be established. In the form of a consortium for instance (den Heijer & van der Voordt, 2004).

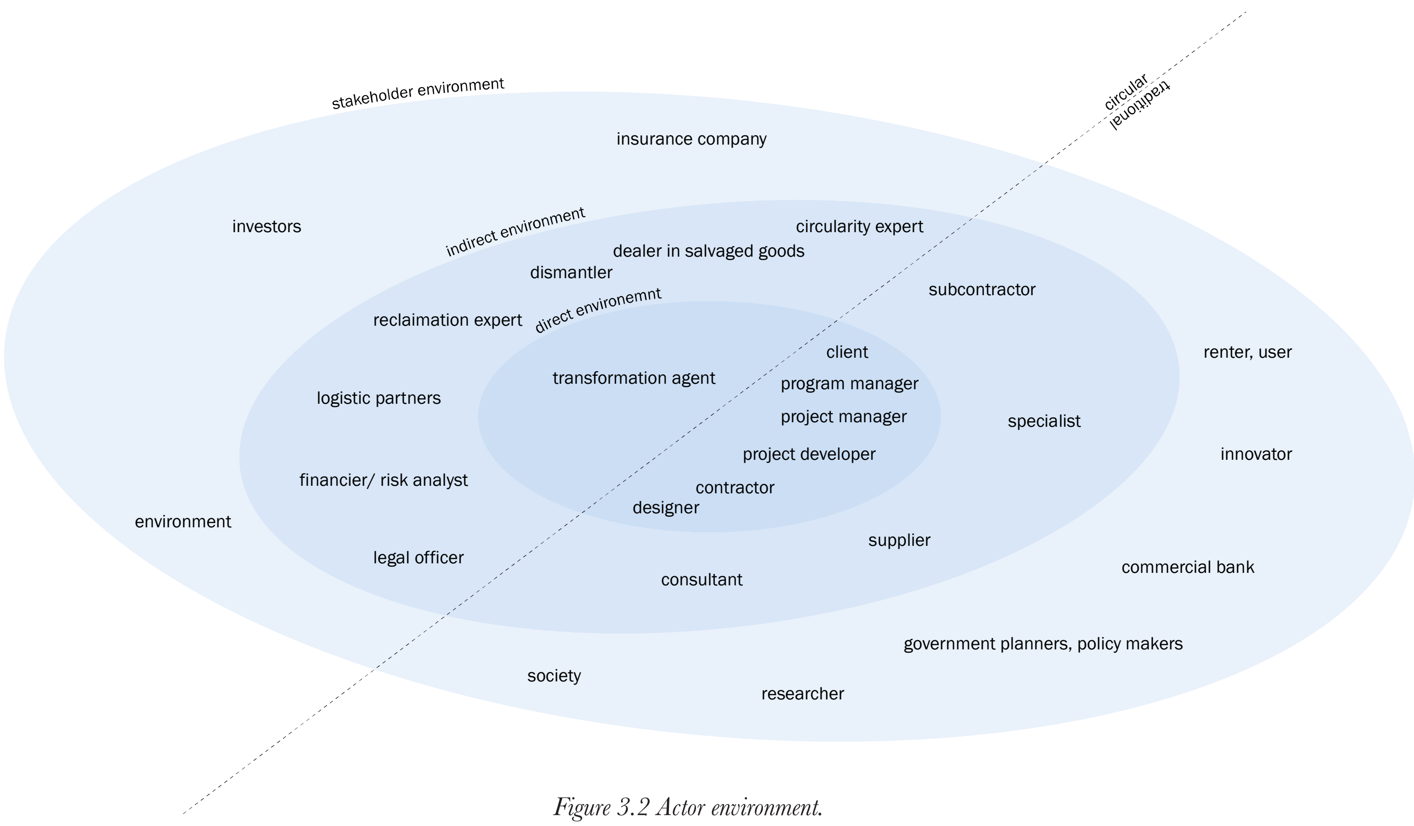

Figure 3.2 Actor environment.

Certain decisions that are made during the building process (as discussed in section 3.1 and 3.2) (immediately) influence the actor network. For instance, the CS 'functionality without ownership' couples decision-making power and responsibility. In this model, ownership and responsibility are located at the supplier. At the end of life the supplier takes back the building components. In case the supplier does not want to take back the components, the materials should be returned to the resource supplier or government. According to Rau & Oberhuber (2016) the supplier should not become the owner, but should only temporary obtain the right to have authority over use of materials and components. This structure requires *transaction* of materials and components. Thereby, this

CS poses new roles on certain actors. Moreover, probably, the actor that gains decision-making power over the transaction structure, will have (increased) influence on the decision-making. Figure 3.3 demonstrates this principle. In this case a consultant owns the transaction structure and facilitates agreement between a client or user and a supplier to implement functionality without ownership. The decision-making power of the transaction structure owner should be controlled. As concluded by Schouten (2016) requirements or restrictions need to be in place to prevent abuse of this decision-making power.

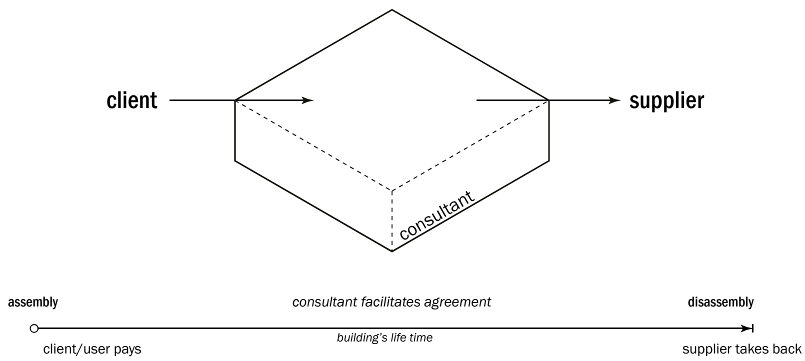

Figure 3.3 CSs could impose different modes of responsibility and ownership, this influences decision-making, since new or other actors obtain increased influence over decision-making if they own or are responsible over a transaction structure (Schouten, 2016; Rau & Oberhuber, 2016).

3.4 Contextual factors

In addition to the aspects discussed previously, literature indicates that some aspects can be identified that seem to influence the building process or behavior of actors in the background. These are the following aspects: contract & form of collaboration, evaluation tools, and goodwill & mindset. It could be that the case study research identifies additional or other aspects.

Contract & form of collaboration

Many authors indicate collaboration as an promoting factor for implementing circularity (Pomponi & Moncaster, 2017). The building and decision-making process is subject to the contractual and collaborative context in which the project takes place. Different types of contracts provide different forms of collaboration. This typically withholds formally established relations and influence on the decision-making process. For instance, this includes the formal form of collaboration and constellation of the project team. On the other hand, authors indicate that circularity could mean that different or new relations and collaborations need to be established (Addis, 2006). It could be that collaboration between demolition firms and suppliers, or between demolition firms and designers becomes beneficial (Koutamanis et al., 2018).

Evaluation tools

The past decades, a wide range of certificates and evaluation tools have been developed to measure or certify implementation of circularity. These measurement and certification processes are usually time-consuming and require intensive documentation and transparency of information (Kibert, 2013). A certificate (i.e. BREEAM, or environmental building declarations) should be issued by an independent third party organization (Kibert, 2013).

Goodwill & mindset

Several authors provide goodwill or mindset as an important requirement for implementing circularity. In other words, actors should be enthusiastic about and preferably have experience with circularity. Commitment from the project team and involved actors is important to be willing to choose for circular scenarios, which sometimes could increase risk or uncertainty (Addis, 2006). Therefore, selection of the *right* project team and involved actors is important. Innovative and collaborative actors are beneficial to the building process and implementation of circularity.

3.5 Conclusion

A glance at the research questions, shows that some topics are of interest, these are: involved actors and their influence, indication of decisions made on circularity, and indication of important moments in time (when these decisions should be made preferably). The above provided literature study provides information on these topics. This is summarized in the analytical framework (see Table 3.7).

It must be noted that these decisions on circularity should be considered with respect to the 'beginning of life' and 'end of life' scenarios. In other words, strategies and types of materials as input and as output should be considered. Based on the framework on circular patterns, Table 3.3, the topics that should be discussed and decided are provided in Table 3.7. Preferably, decisions regarding these topics are made early on in the building process. Since, as noted in section 2. Theoretical background, this stage offers room to implement changes.

Table 3.7 Analytical framework as concluded from the literature study.

Topic	Aspects	Research question

Actor network	• Actors (traditional and unconventional actors)
	   • Resources
	• Relations
	   • Formal, informal
	   • Previously established relations, long-term
	• Positions (roles)
	   • Centrality
	• Influence on decision-making
		"Which actors are involved in the building process of circular building projects?"
		
		"Which actors influence decision-making on circularity?"

Decision-making process	• Involved actors that influence decision-making
	• Rounds/decisions
	   • Patterns
	      • Circular strategies (CSs)
	      • Design strategies (type of materials, layers)
	      • Upfront and afterwards scenarios: beginning and end of building's life time
	• Time
	   • Phases of the building process
	   • When does it take place (early on)
		"Which actors influence decision-making on circularity?"
		
		"What decisions on circularity are made?"
		
		"When are decisions on circularity being made?"

Contextual factors	• Contract & form of collaboration • Evaluation tool • Goodwill & mindset	-

Notes

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4. Method

This section explains the research method. The introduction already glanced briefly at the research method: case study research. This section provides reasons for choosing this method, explains the selection of cases, discusses the research design, describes the data gathering, and last, provides limitations of this research method.

4.1 Case study research

Case study research will provide a useful method for this research. As in line with the research objective, this method offers the ability to gain knowledge from practice. This method helps to grasp the specificities of these cases in their particular context by offering an in-depth, qualitative, and empirical research method. Thereby, case study research is a means to reveal (in detail) the way these projects have dealt with implementing circularity in the building process. By use of a literature study (see section 3. Analytical framework), theory is provided on these topics as well as criteria to analyze the cases upon. See also Figure 4.1 for the method of this research.

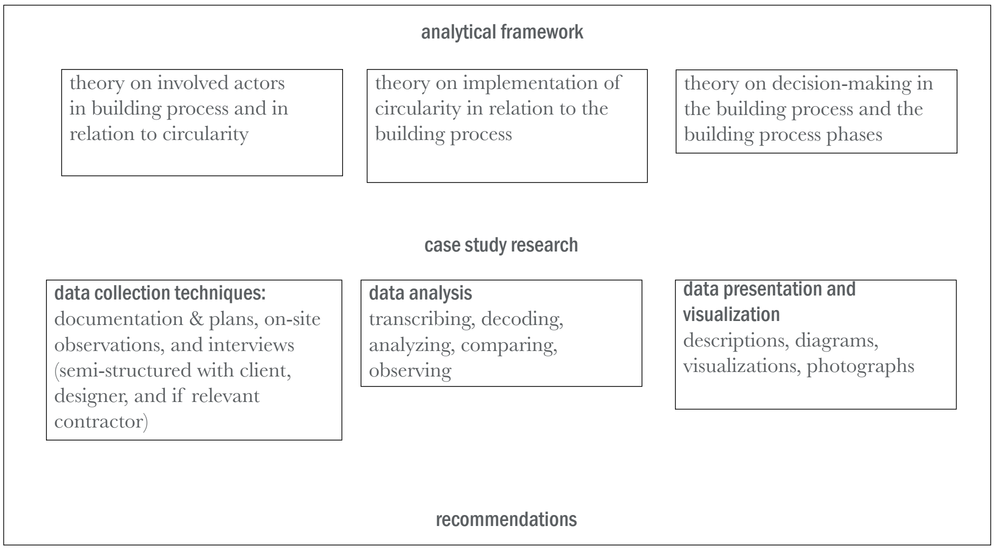

Figure 4.1 Method of research.

4.2 Finding cases

The precedent research (part I) focused on the following three cases: the ABT office in Delft by BiermanHenket built in 2001, the Townhall in Brummen by RAU built in 2013, and The Green House in Utrecht by cepezed built in 2018. These cases were chosen with certain criteria in mind. In order to determine the suitability of these cases for this research, these cases need to be re-evaluated. Table 4.1 provides an overview of interesting building projects that could be studied for this research. These projects are all located in the Netherlands. This provides ground for comparison, since these projects have a fairly similar and comparable building process. These projects were gathered by use of desk research and by means of consultation of experts – Marijn Emanuel (Madaster) and Tillmann Klein (TU Delft).

4.3 Selection of cases

In order to select three cases from the previously provided long list, the following criteria should be met. The project should:

- have a circular-related ambition;
- be recently built or currently constructed (2010 or later);
- have accessible information available about involved actors;
- have accessible information available about applied circular strategies;
- have accessible information available about the decision-making process;
- have accessible information about involvement and influence of actors in the decision-making process.

As can be seen in Table 4.1, these criteria are applied to each project. It appears that the more recent projects (or even projects currently under construction) have little information available with respect to these criteria, whereas more 'older' projects have more documentation available.

Table 4.1 Long list of projects.

project	criterion							
	circular ambition	current (2010 or later)	information available about actors	information available about circular strategies	information available about decision-making	information about actors involved in decisions	renovation or new	count
ABT office, Delft, BiermanHenket, 2001	x		x	x		x	new	4
The Green House, Utrecht, cepezed, 2018	x	x	x	x	x	x	new	6
Townhall, Brummen, RAU, 2013	x	x	x	x	x	x	new (addition to monumental villa)	6
Triodos kantoor, Driebergen-Zeist, RAU, under construction	x	x	x	x			new	4
Liander, Duiven, RAU, 2015	x	x	x	x	x	x	renovation	6
Drukkerijloods Binckhorst, The Hague, Kraaijvanger, under construction	x	x	x				renovation	3
People's Pavilion, Eindhoven (DDW), Bureau SLA, 2017	x	x		x			new	3
Circl, Amsterdam, ArchitektenCie, 2017	x	x	x	x			new	4
Temporary court of justice, Amsterdam, cepezed, 2016	x	x	x	x			new	4
Waste deposit station, The Hague, Wessel van Geffen Architecten & Superuse Studios, 2016	x	x	x	x			new	4
New headquarters of the Council of the EU, Brussels, Philippe Samyn and Partners, 2016	x	x					new	2
XX office, Delft, XX archiects, 1998	x		x	x			new	3
Municipal offices, Venlo, Kraaijvanger, 2016	x	x	x	x			new	4
Townhall, Eindhoven, !MPULS (consortium), under construction	x	x	x				renovation	3
Edge Olympic, Amsterdam, Architecten Cie, 2018	x	x	x	x	x		renovation	5
Fellenoord 15, Eindhoven, UNStudio, 2017	x	x	x		x		renovation	4
De Knoop Kazerne, Utrecht, Rijboutt, Ballast Nedam, 2018	x	x	x	x		x	renovation	5

These criteria have been applied to each case individually. The final choice for three cases should also keep in mind the combination of the three cases. For instance, it would be more interesting to choose three cases that each have different involved companies – for example, different architecture offices. Additionally, it would be interesting to study a renovation project. The Green House, Townhall Brummen, and Liander score high. These projects are, however, all new projects, except for Liander. Liander includes the renovation of existing offices. Unfortunately, Liander has the same involved architecture office as the Townhall in Brummen. In relation to other renovation projects, EDGE Olympic and De Knoop score high. The Knoop has the same architect as The Green House, therefore EDGE Olympic is preferred.

On the basis of these criteria, the following cases are particularly suitable for this research:

- Townhall in Brummen by RAU built in 2013
- The Green House in Utrecht by cepezed built in 2018
- EDGE Olympic in Amsterdam by Architekten Cie. built in 2018

4.4 Research design

With respect to the research question and sub questions, the case study research should investigate certain aspects. Based on the previously provided literature study and subsequent analytical framework, criteria to study can be extracted, see also Table 3.7 from section 3. Analytical framework. The criteria that will be investigated for these cases are provided below.

It must be noted that the investigation of these criteria relies on information gathered from interviews (and documentation). Therefore, this method is qualitative. For each criteria it is shortly described how information in relation to that criterion was identified by decoding the transcripts of the interviews.

4.4.1 Criteria

As can be seen in the analytical framework the following criteria seem interesting: the actor network including actors & resources, relations, positions, and influence on decision-making; and the decision-making process over time including involved actors and influence on decision making, rounds, and position in time. Below an overview of interesting criteria for both investigating the actor network and decision-making process are discussed and provided.

4.4.1.1 Actor network

Methods for studying the actor network can be found in the field of actor network theory. With respect to this study the work of Enserink et al. (2010), Teisman (2000), van Ruijven (2016), and Klijn, Bueren, & Koppenjan (2000) is utilized. Oftentimes, these studies also include stakeholder analysis. For this study only the involved actors are considered, so parties that (could) have a stake or interest are excluded. In contrast to the field of public policy, in this field – the building industry – it is presumed that the actors involved in the organization for constructing a building are working towards the same goal. Since the involved actors constitute in a temporary organization that is formed by the client.

Actors

An actor is defined as *"a social entity, person or organization, able to act on or exert influence on a decision"* (Enserink et al., 2010, p.80). With respect to this context – a building process for construction of a building – an actor is part of the project team or formally involved by means of a contract or by means of advice or consultation. With respect to the data, an organization is defined as *one* actor acting in a certain role (i.e. contractor, client, subcontractor, etc.). If the interviews identify a significant role of one person within an organization, this person is considered as a separate actor from its organization.

An actor is involved, because he or she could offer something to construct the building. This offer is termed a 'resource', which is defined as *"the practical means that actors have to realize their objectives"* (Enserink et al., 2010, p.81). These resources, based on Enserink et al. (2010), could be categorized as follows:

- Information & knowledge (and skills)
- Instruments (i.e. subsidies)
- Manpower & money
- Authority (formal power)
- Position in the network (support from or access to other actors, also outside of the network)
- Organization (ability to mobilize and use resources effectively and efficiently)

The interviews identify the main resources of each actor. These resources are categorized according to the above provided categorization. This is based on information provided by the interviewees. In the interviews the interviewees provide information on the main 'practical means' by which actors contribute to the process.

Relations

A relation displays a *connection* between actors. A relation indicates exchange of information or coordination between actors (van Ruijven, 2016). If actors interact on a weekly basis the line is thick. If actors interact on a biweekly basis (or less) the line is thin. This is identified by means of the interviews. The interviews provide information regarding the frequency and type of communication with or between certain actors, i.e. physical contact (i.e. meetings), or contact by mail or telephone.

The relations between actors could be informal or formal (Enserink et al., 2010). Formal relations are relations that are documented in formal documents or procedures, such as contracts (Enserink et al., 2010). With respect to these case studies, formal relations could be established by means of a contract between the client and contractor(s). Informal relations are relations between actors that are not prescribed in a contract or other formal document (Enserink et al., 2010). These informal relations are part of the actor's personal network and could exist of relations between actors based on previous projects. With respect to this research, both formal forms of contact as well as informal forms are of interest. The interviews could help to identify both formal and informal relations and forms of contact. In addition, actors could obtain long-term relations. In other words, the actor could have already collaborated in the past on previous projects. Previously established relationships between actors is also discussed in the interviews.

Positions

The positions of the actors in the actor network relate to their centrality in the network. Centrality is defined as *"the number of connections between a node and other nodes"* (van Ruijven, 2016, p.127). This can be applied by determining whether there is communication between an actor and another actor. This is identified by means of the interviews, in which the interviewees provide information on the connections with and between actors. For instance, if actor X communicates with five other actors, which is in this network the highest number of relations, then actor X can be positioned in the center of the network. Thus, the higher the number of relations, the more central the actor. The lower number of relations, the less central the actor.

Influence on decision-making

Influence on the decision-making is defined by the size of the node. The largest node is defined as high influence on the decision-making. In other words, this actor is involved in all significant decisions (more than 4 rounds). The middle size node can be defined as some influence on the decision-making, or involvement in most significant decisions (involved in 2 up to 4 rounds). The smallest node is defined as little influence on the decision-making, this actor is not often involved in significant decisions (involved in less than 2 rounds).

The above described criteria for investigating and visualizing the actor network are outlined in Table 4.2. A visualization of the actor network as provided by van Ruijven (2016) can be seen in Figure 4.2.

Table 4.2 Criteria for investigating and visualizing the actor network for case study research.

Criteria	Visualized as
1. Actors	A node relating to a certain role and organization.
1.1. Resources	
1.1.1. Information & knowledge (and skills)	
1.1.2. Instruments (i.e. subsidies)	
1.1.3. Manpower & Money	
1.1.4. Authority, formal power	
1.1.5. Position in the network	
1.1.6. Organization	
2. Relations 2.1. Frequency and intensity of exchange 2.2. Informal and formal relations 2.3. Previously established relations	Line between two nodes. Thick line for weekly exchange, thin line for biweekly exchange.
3. Positions 3.1. Position of node 3.2. Centrality	Position of node, degree of centrality determined by the number of connections between actors.
4. Influence on decision-making	Size of the node, biggest node for high influence (involved in > 4 rounds), middle node for some influence (involved in 2 ≤ x ≤ 4 rounds), and small node for limited influence (involved in < 2 rounds).

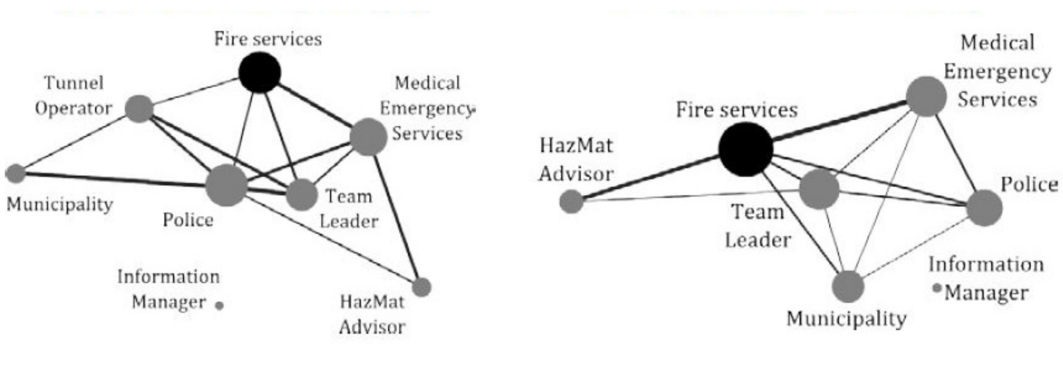

Figure 4.2 Example of a visualization of an actor network by van Ruijven (2016).

4.4.1.2 Decision-making process

The work of Teisman (2000) on decision-making originates from the field of public policy. It discusses models for unraveling complex decision-making processes. Its relevance for this study can be found in its visualization of the decision-making process, including the involvement and roles of multiple actors and their influence on the decision-making (Teisman, 2000). Figure 4.3 provides a visualization of the concept of decision-making based on the rounds model by Teisman (2000). This visualization includes rounds, actors, and decisions. Figure 4.4 depicts a further developed visualization of the decision-making process based on the rounds model by Klijn & Koppenjan (2016). The composition of this model and its concepts will be discussed below.

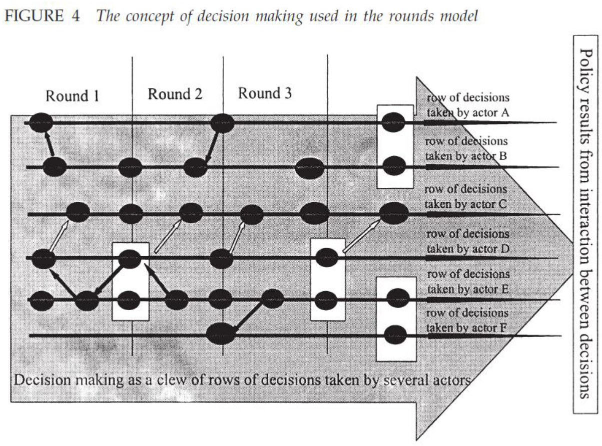

Figure 4.3 The concept of decision-making used in the rounds model according to Teisman (2000).

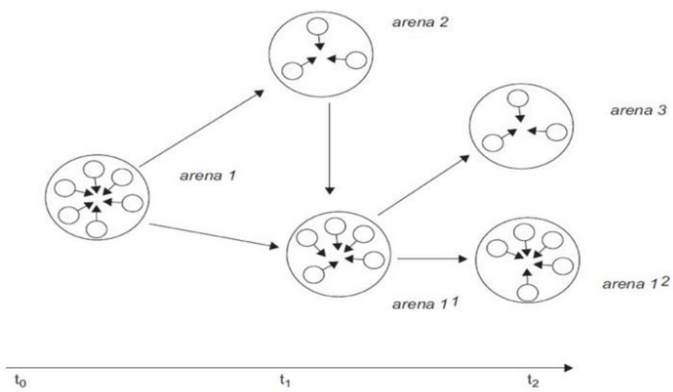

Figure 4.4 Visualization of decision-making process as a rounds model based on Klijn & Koppenjan (2016).

The building process consists of multiple decisions. Preliminary to a decision is made, consultations and discussions take place, during which certain actors are involved and collaborate. This process is defined as a round. A round is a sequence of several moments in time in which certain consultations and discussions take place to come to a decision (Klijn et al., 2000). Each round relates to a certain topic and each round leads to a decision regarding that topic (Klijn et al., 2000). The identification of decisions or decision rounds is subject to assumptions and subjectivity (Teisman, 2000). Often the decision-making process changes course multiple times (Teisman, 2000). A round is positioned in time where the most crucial decision(s) regarding this topic is/are made. A round can take place sequential or in parallel to other rounds (Klijn et al., 2000).

For this thesis, the position in time of rounds regarding *circular decisions* is of interest. Specifically, it is interesting to find out what rounds and how many take place early on in the process. Since, as previously argued, it is anticipated that early on decision-making on circularity, benefits its implementation.

As based on the analytical framework, decisions regarding circularity are identified in the literature study, these are summarized in Table 3.3 in section 3. Analytical framework. These relate to decisions on certain patterns, circular strategies (CS), design strategies, and layers to which they are applied. These could be decided upon as an upfront or afterwards scenario for the building. Besides, involved actors and position of rounds in time should be investigated for the decision-making process. The criteria for the decision-making process are summarized in Table 4.3.

This thesis relies on data as gathered from the interviews to identify and position certain rounds. Particularly, rounds regarding circularity, in other words rounds relating to circular decisions, are of interest. The interviewees have, by means of asking certain questions (see also Appendix II), described decisions and described who were involved in and influenced decision-making. This relates to both formal and informal influence on decision-making. In addition, the interviews contain information regarding the moment in time (phase in the building process) that these decisions took place. This information is used to identify and position certain rounds, and subsequently determine the involved actors.

Table 4.3 Criteria for investigating and visualizing of decision-making process for case study research.

Criteria	Visualized as
1. Decision-making process	
1.1. Involved actors that influence decision-making	A node relating to a certain role in accordance with the actor network.
1.2. Rounds 1.2.1. Patterns 1.2.1.1. Circular strategies 1.2.1.2. Design strategies 1.2.1.3. Upfront and afterwards scenarios 1.2.1.2. Layers	An outlined circle concerning a pattern relating to subsequent circular strategies, design strategies, and layers and applied as upfront or afterwards scenario. This is identified from the interviewees description of decision regarding circularity.
1.3. Time 1.3.1. Phases of the building process including initiation and preparation phase	Position on the x-axis in relation to phases in the building process (initiate, prepare, design, build, finance, maintain, operate).

4.6 Data gathering

This section describes the data requirements for the case studies research. The case study research relies on availability of data. The accessibility of required data has already been considered as an important aspect during the selection of the cases. In order to analyze the cases properly, information is required about certain aspects. Therefore, in order to conduct the case study research, data will be extracted from the following approaches and domains:

- Reputational approach: information about actors is gathered by asking 'key informants' about relevant actors, their resources, position, relations, influence, etc. (Enserink et al., 2010).
  - By means of semi-structured interviews (primary sources) with clients, designers (and contractors). By decoding the transcripts of the interviews relevant data is gathered.

- Text, image & phenomenon analysis:
  - By means of documents & plans (secondary sources).
  - By means of on-site observations.

After gathering these data, an analysis can be performed which will result in textual elaborations and schematic diagrams of the actor network and decision-making process.

The previous research has provided the researcher with a thorough overview of the Townhall in Brummen and The Green House in Utrecht. Additional documentation, however, will be necessary to study the aspects for this research. Besides, information needs to be gathered for the third case, the EDGE Olympic building. This information is mainly available by means of online and requested documents, and contact with involved actors.

With regards to the feasibility of this research, and in particular the accessibility of the data, the following should be kept in mind. Extensive information for two of the three cases has already been collected during the previous research (part I). Additional information can be gathered via online media, documentation, and contact with the involved actors in the building processes of these cases. Several names of involved actors and their contact details are available. However, attention must be paid to the difficulty and time-consuming characteristic of planning and executing interviews. The preparation of the interviews, including the scheduling of the interviews, must be done on time. Appendix I provides an overview of the interviews that were conducted and their scheduling. Appendix II provides an overview of the interview set up.

4.7 Limitations

It must be kept in mind that the results from the case study research apply to these particular cases. External validity must be considered with these cases and their specificities in mind. Subsequently, the results from the case study research will be used to make recommendations. Concerning the external validity, these recommendations must consider the context of these cases and their limited generalizability. Probably, internal validity will remain intact, because the cases are studied in their specific context. The case studies could offer useful in-depth information which would not become visible by using a more broader applicable method such as a survey (Verschuren & Doorewaard, 2010). Besides, this method will help to relate the results to its particular context – the building process and construction industry.

It must be noted that the actor networks and decision-making processes that will follow from the case study research are subject to subjectivity. Since the identification of and position of actors and decision-making processes is subject to the eye of the researcher. Each researcher (and involved actor) could have a different perception on these processes (Teisman, 2000). Besides, the actor network provides a somewhat static classification, although it is determined over time, the constellation of actors is subject to constant change (Enserink et al., 2010). Moreover, as already indicated, the research relies on interviews as the main source for identifying the actor network and decision-making process, thereby providing qualitative data.

With respect to the interviews, the quality of the gathered data could be limited. Generally, not everyone is willing to share sensitive or personal information regarding the actor network and decision-making process. The information could be strategically desirable (Enserink et al., 2010). Multiple interviews with key informants could help to overcome this limitation. This thesis relies on two (or three) interviews per case with the client and designer. Information from the interviews must be crosschecked with other sources, such as documents. In addition, it must be indicated if information is uncertain or missing (Enserink et al., 2010).

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Notes

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J., & Bots, P. (2010*). Actor Analysis.* In Policy Analysis of Multi-Actor Systems (pp. 79–108). The Hague: Lemma.

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5. Cases

This section introduces the three cases. It provides some general, contextual aspects such as the location, function and program, type of project, the actors that participated in the project, and its circular ambition.

5.1 Case 1: Townhall Brummen

The Townhall located in Brummen provides semi-permanent accommodation for the municipality of Brummen. This project has a public client (local municipality of Brummen) who will also become the user of the building. The building is programmed to serve as their accommodation for a minimum of 20 years (Rau, 2013).

The client provided an ambition for this project. They demanded a sustainable building with a temporal life time. The parties that were invited to design and construct, translated this vision into a building that demonstrates some *circular* decisions – such as demountable connections and renewable materials. Although, at that time this was probably perceived different, since circularity was not a common known term then (Radermacher & BAM, 2012). Freely translated this vision was formulated as; *"the most sustainable building of the Netherlands with maximum modularity against minimal costs to accommodate the municipality for the coming 20 years in a qualitative and comfortable accommodation which is representative in its surroundings"* (van Hulst, Gemeente Brummen, & Haskoning, 2011, p.6).

This project took place during the financial crisis (it was initiated in 2008). This influenced the project, for instance, the municipality could demand a relatively low price from market parties. On the other hand, this strict budget and limited time span resulted in certain choices that did not always benefit their vision and circularity. For instance, the existing municipality building was almost completely demolished ("Her- en verbouw gemeentehuis Brummen," 2018).

Figure 5.1 Townhall in Brummen by RAU built in 2013 (source: RAU).

5.2 Case 2: The Green House

The Green House is advertised as a circular horeca pavilion (van der Wee, 2018). The Green House is a pavilion that houses commercial functions: a restaurant, meeting rooms, and a greenhouse (or 'urban farm') (van der Wee, 2018). It is located in Utrecht, near the central station at the Croeselaan adjacent to the Moreelsebrug and the 'Rijkskantoor de Knoop' (located in the former Knoop barracks) (Wind, 2018).

The Green House is part of the redevelopment plan for the Knoop barracks. For the Knoop, instead of demolition, a more material friendly option was preferred. Hence, the decision was made to redevelop this former military basis into a government office building (Crone, 2018). The consortium R Creators was contracted to execute the work for redevelopment of the Knoop and The Green House. R Creators is a corporation that has Strukton (80%) and Facilicom (20%) as shareholders and the executive parties are Strukton (45%), Ballast Nedam (45%), and Facilicom (10%) ("Definitieve gunning Rijkskantoor De Knoop," 2015). These actors developed the Knoop and The Green House together with cepezed (as architects), Fokkema & Partners (as interior designers), Rijnboutt, and Brakel Atmos (Crone, 2018).

The Green House was built with a temporal life time in mind, which was not necessarily informed by sustainability ambitions but merely dictated by the urban planning scheme that stated another office building is to be constructed in 15 years from now at this location. Therefore, the building should only last for 15 years at this location. The contractors translated this objective into a circular, demountable building (Economic Board Utrecht & Cirkelregio Utrecht, 2018). After the 15 years life span, the aim is to dismantle the building, and preferably continue its life at another location. Therefore, preparations were made to make the building demountable and rebuildable (Wind, 2018).

Figure 5.2 The Green House in Utrecht by cepezed built in 2018 (source: cepezed).

5.3 Case 3: EDGE Olympic

This project includes the renovation of and extension to a former nineties office building on an prime location in Amsterdam ("EDGE Olympic," 2018). Before the renovation, this office building was known as 'Olympic Plaza' built in 1990 (de Architekten Cie., 2018a). After completion in May 2018, the building houses multiple offices in a multi-tenant constellation (Vos, 2018; de Architekten Cie., 2018b). The building is characterized by implementation of multiple technologies to facilitate the user and provide a comfortable and healthy environment (Vos, 2018). Together with Epicenter, Edge Technologies takes care of the exploitation of the building (Jansen, 2018). Edge Technologies is part of OVG Real Estate (Lachmeijer, 2018; Timmerman, 2018).

As explained, this project includes the renovation of an existing building and construction of an additional floor on top of the existing building. This requires that all actors are willing to participate, for which they need to be able to oversee and bear the risks involving a renovation project, instead of choosing for a perhaps more low risk and cheaper option: demolition.

As explained, the building will be rented by multiple tenants. The current tenants are: Edge Technologies (part of OVG Real Estate), Software Improvement Group (SIG), Ebbing, and EVBox (van Leeuwen, 2018). OVG Real Estate is the owner of the building. During the building process Edge Technologies was involved, the other users did not participate in the building process.

Figure 5.3 Former office building located Fred. Roeskestraat in Amsterdam, currently the building has been transformed into a multi-tenant office building (source: left image: https://lievense.com/project/olympic-plaza-amsterdam/; right image: Ossip van Duivenbode)

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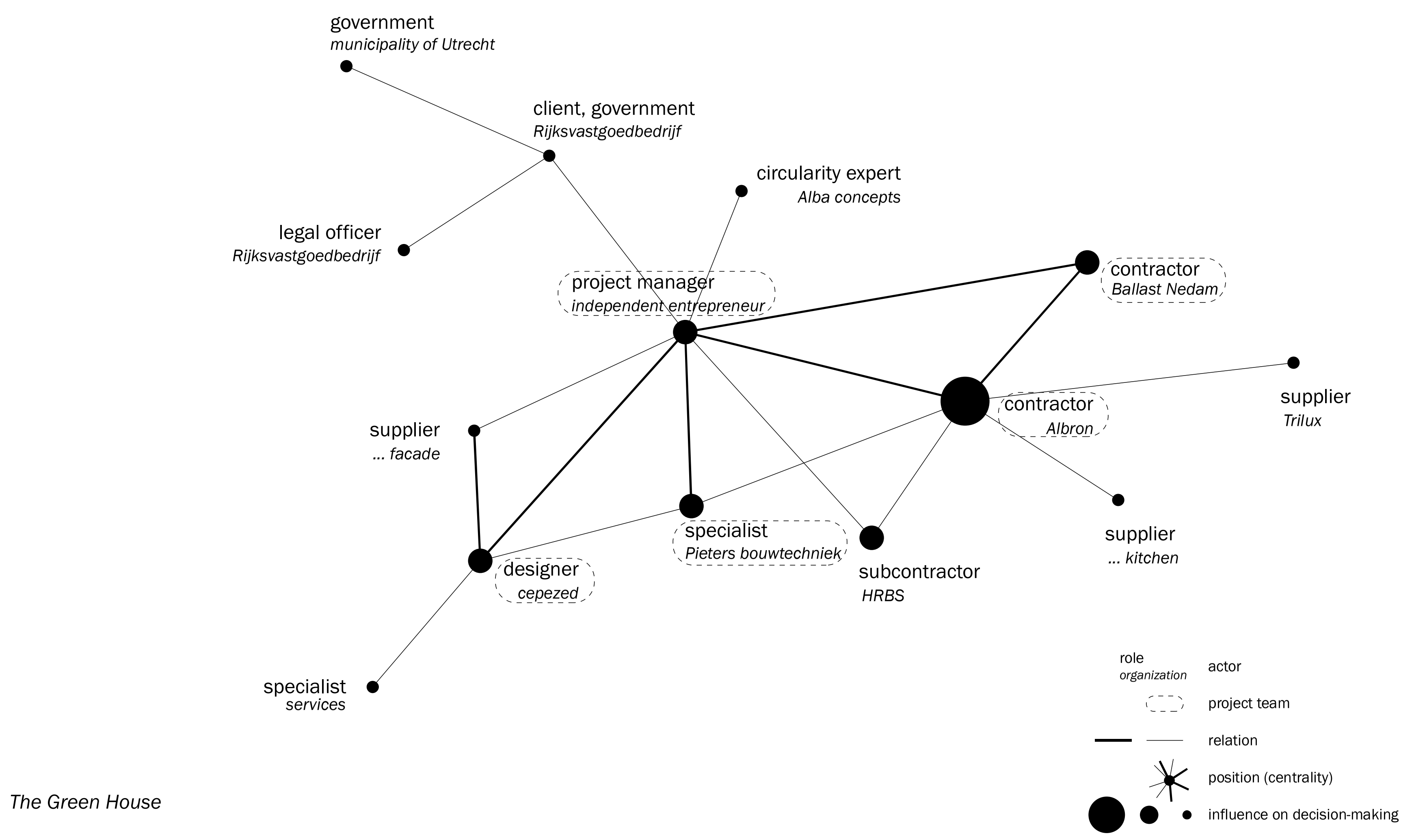
6. Findings

This section provides findings from the case study research. These findings are structured in line with the analytical framework as concluded from section 3. Analytical framework. It must be kept in mind that this section relies on data gathered from the interviews. Relevant data has been gathered by decoding the transcripts in line with the criteria as provided in section 4. Method. As explained in the method (section 4. Method), the visualizations are based on careful analysis of data that is gathered from the interviews and subsequent documentation.

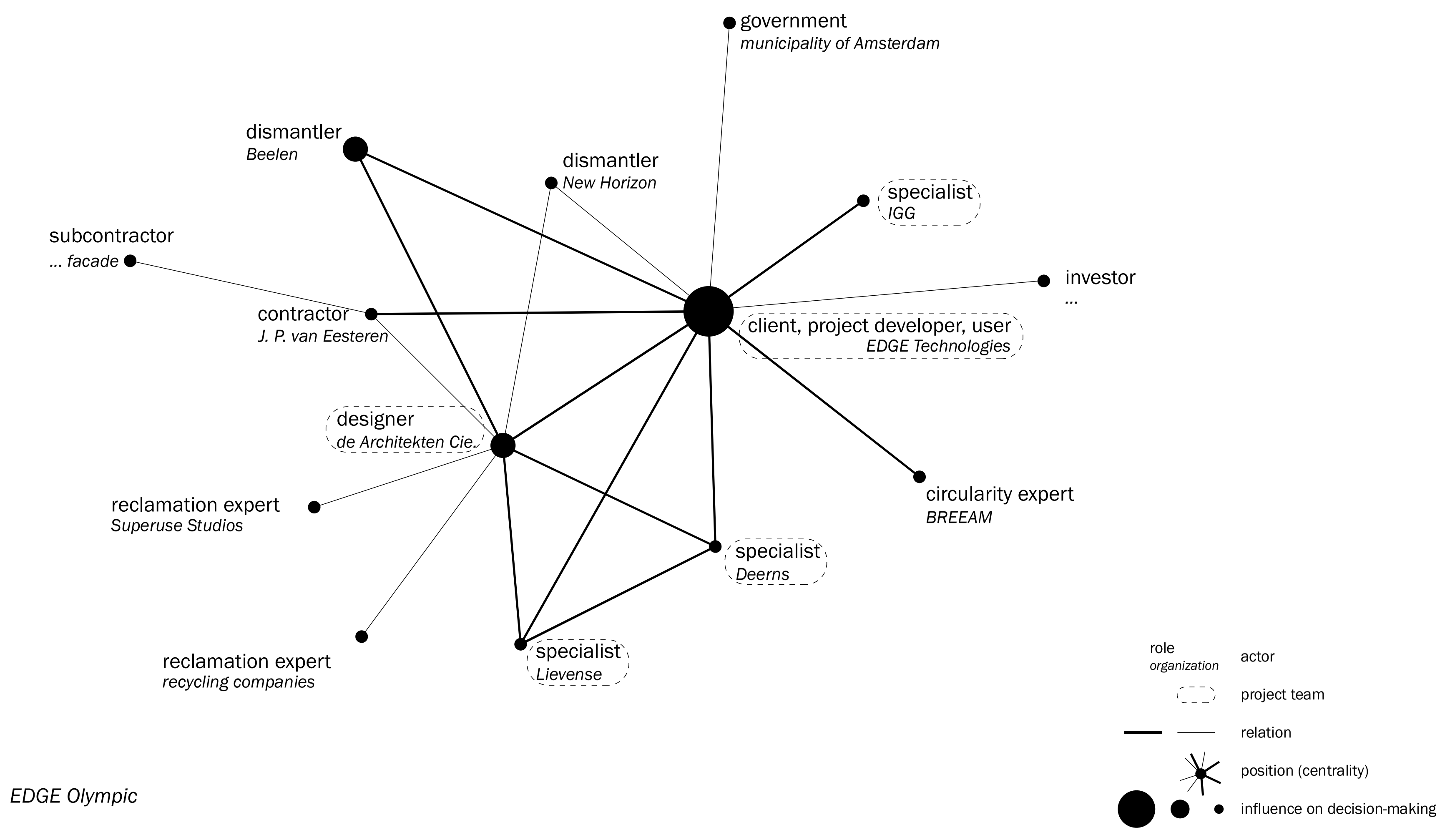
This section continues as follows. First, analysis of the actor network for each case study is presented and discussed, including the involved actors, their relations, their positions, and their influence on decision-making. Second, analysis of the decision-making process regarding circularity is presented and discussed, this includes involved actors, rounds and decisions, position of rounds in the building process, and influence of involved actors on decision-making. Third, contextual factors are discussed, which seem to influence the behavior of actors in the actor network and decision-making process, but are outside the scope of this research. Fourth, this section ends by providing conclusions.

6.1 Actor network

For each case, the actor network is visualized. This includes information on the involved actors, their relations, their positions, and their influence on decision-making, see Figure 6.1. The composition of the actor network and its included aspects is based on the method as described in section 4. Method. A description of the actor network and its most significant standouts is provided in this section.

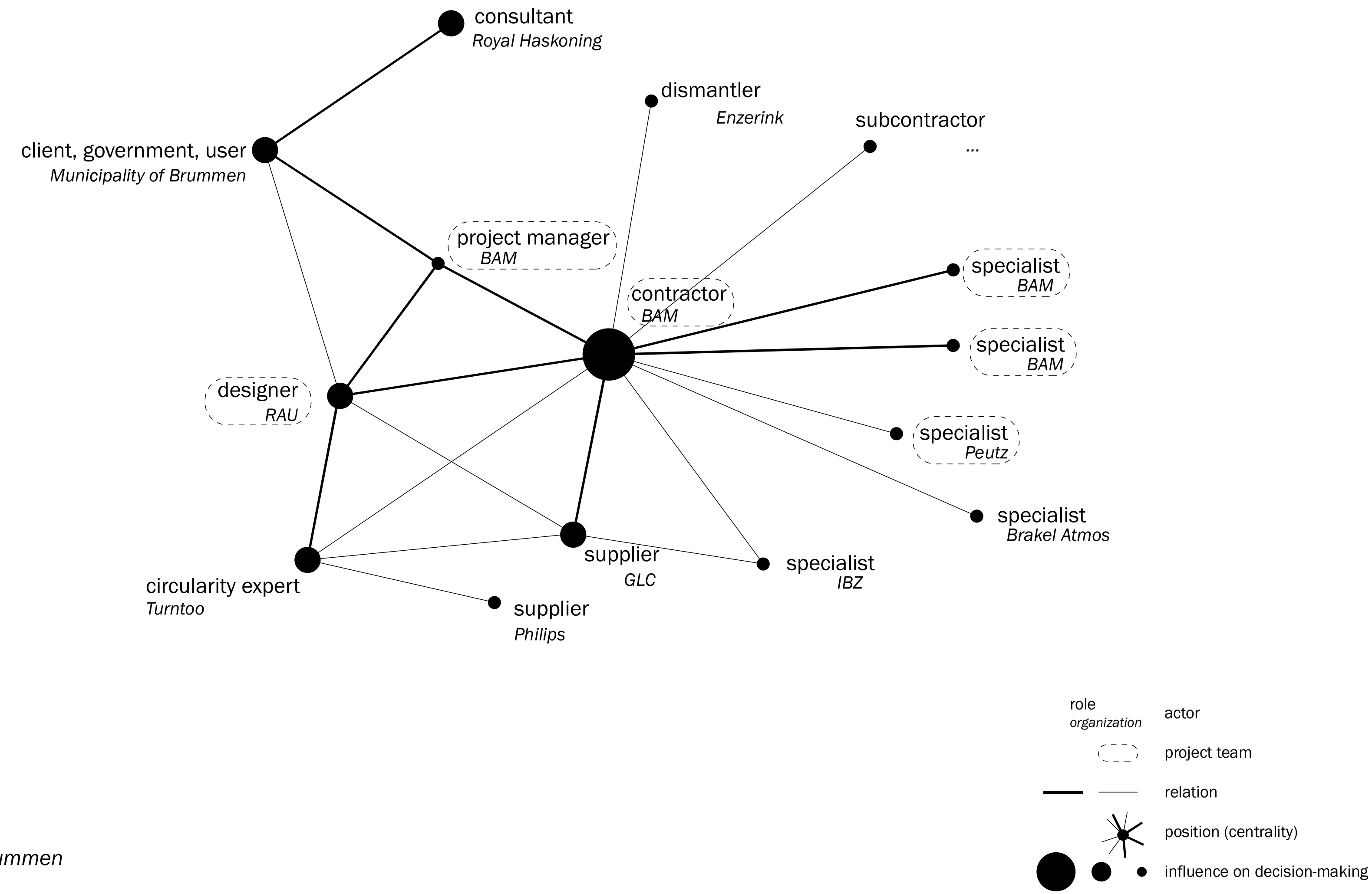


The Green House



EDGE Olympic

Figure 6.1 Actor network including involved actors, their positions, their relations, and their influence on decision-making, for Townhall Brummen, The Green House, and EDGE Olympic, respectively.



Townhall Brummen

6.1.1 Actors

A long list of (almost) all actors and their main resources can be found for each case in Appendix III. The actor networks in Figure 6.1 include the most significant actors, as identified from the interviews and relevant documentation. As can be seen in Figure 6.1, the actors that are part of the project team are depicted by a dashed outline.

For the Townhall Brummen, the following actors are part of the project team: contractor (BAM), project manager (BAM), designer (RAU), and specialists regarding structural engineering, building technology, and services. The client (municipality of Brummen) hired an external advisor (consultant from Royal Haskoning). As can be seen in Figure 6.1, this consultant is not part of the project team. This actor is involved via the client. This advisor advised the municipality, amongst others, to use a design and build contract, since this type of contract would provide freedom for the market to fulfil and develop the sustainable ambitions (see interview with Joep Radermacher, 2018). Moreover, as can be seen, the project manager is from the same organization as the contractor (BAM), but is identified as a separate actor. In this case, the project manager acted as a separate entity from its organization. The project manager possesses different resources and shows different involvement and influence on decision-making. For instance, the project manager indicates in the interview that he is responsible for communication between the client and the contractor and designer, and he examines whether the project fulfills the requirements as provided for by the client (see interview with Joep Radermacher, 2018). Furthermore, subcontractors, suppliers, specialists, a dismantler, and a circularity expert were involved, but not part of the project team.

In the case of The Green House contractors from the consortium (Albron, Ballast Nedam), a project manager, a designer (cepezed), and a specialist (Pieters bouwtechniek) are involved in the project team (see interview with Jaap Bosch, 2018). Other actors included in the actor network, but not part of the project team, are: the client, the government, suppliers, subcontractors, specialists, a circularity expert, and a legal officer.

In the case of EDGE Olympic the contractor is not part of the project team, however, the client is part of the project team (see interview with Eric van Noord, 2018). Together with the client, the project team consists of the designer (de Architekten Cie.), and specialists regarding structural engineering, building costs, and services. In addition, subcontractors, an investor, the government, and several circular-related actors are involved. These circular-related actors are defined as: dismantlers, reclamation experts, and a circularity expert.

As can be seen in Figure 6.1 and Appendix III, all cases involve experts or specialists from the field of circularity, such as circularity experts, dismantlers, reclamation experts, etc. These actors mainly contribute to evaluating choices in relation to circularity or by providing advice (see interview with Peter Eitjes, 2018; and Constantijn Berning, 2018). The three cases show that these experts were not part of the project team. The project team constitutes of traditional actors, such as designer, client, contractor and specialists regarding structural engineering and building physics.

Resources

For each actor the main resource is identified. In section 4. Method a resource is defined as *"the practical means that actors have to realize their objectives"* (Enserink et al., 2010, p.81). Appendix III depicts the main resources that each actor possesses.

The contractor and designer of Townhall Brummen both possess the resource 'position in the network'. This facilitates them in contacting actors outside the network. The client's main resource is 'authority (formal power)'. The actors categorized as circular-related mainly provided 'information & knowledge (and skills)' as their main resource. In addition, the circularity expert (BREEAM) offers the resource 'instruments'. This actor could facilitate in obtaining subsidies (see interview with Anne-marie van Dijk, 2018).

The Green House case shows that the multiple contractors involved in the consortium offer 'position in the network' as one of their main resources. Moreover, the project manager has 'position in the network' and 'organization' as its main resources. As described in section 4. Method, these resources aid in getting support from others (outside the network) and mobilizing the actor network. The client's main resource is 'authority (formal power)'. And the circular-related actors mainly provide 'information & knowledge (and skills)' (see interview with Jaap Bosch, 2018).

In contrast to the other two cases, the EDGE Olympic case shows that the client has multiple resources. These resources are: 'information & knowledge (and skills)', 'authority (formal power)', and 'position in the network' (see interview with Constantijn Berning, 2018). The client is more actively involved compared to the other two cases. In this case, the contractor provides 'information & knowledge (and skills)', 'position in the network', and 'organization' as main resources. The circular-related actors offer 'information & knowledge (and skills)' as their main resource.

For the three cases it appears that a lot of actors possess 'information & knowledge (and skills)' and/or 'manpower & money'. As discussed, some actors possess the 'position in the network' resource. With respect to circularity, this could relate to the ability to become aware of secondhand materials that can be reclaimed. As was the case for The Green House, in this case the contractor and designer used their network to find secondhand materials that can be reused (see interview with Jaap Bosch, 2018). For all three cases, the designers bring in 'information & knowledge' and 'position in the network'. The latter resource is mainly addressed when searching for released secondhand components to provide upfront reuse of components (see interview with Jaap Bosch, 2018; and Eric van Noord, 2018).

6.1.2 Relations

As provided in section 4. Method, a relation indicates exchange of information or coordination between actors (van Ruijven, 2016). In this case a thick line indicates weekly communication and a thin line indicates biweekly (or less frequent) communication. It must be noted that the length of the relations (lines) do not have a meaning.

For Townhall Brummen the frequency of communication within the project team was on a weekly basis and communication with the client happened biweekly (see interview with Annemarie van Dijk, 2018). As can be seen, the more close relations (thick lines) are positioned between actors that take part in the project team. Additionally, close relations occur between some actors from the project team and actors not part of the project team. For this case, these actors outside of the project team in close contact with actors from the project team are: a supplier, a circularity expert, and the client.

This also holds for The Green House, exchange of information and coordination takes place most intensively between actors part of the project team. In addition, a supplier not part of the project team coordinates and exchanges frequently with the designer regarding the façade structure (see interview with Jaap Bosch, 2018)

For EDGE Olympic, close relations occur within the project team and between the project team and the contractor, a circularity expert, and a dismantler. It must be noted that the dismantler was mostly involved during the beginning of the process, the objective to transform an existing office building logically required involvement of a dismantler (see interview with Eric van Noord, 2018). The designer of EDGE Olympic explains that some actors were, on a less frequent basis (thin lines), consulted to discuss circular principles and possibilities (see interview with Eric van Noord, 2018). The designer consulted dismantlers and reclamation experts to gather information and knowledge on circularity. For instance, the designer consulted Superuse Studios (reclamation expert) concerning reuse possibilities of the existing building (see interview with Eric van Noord, 2018). In addition, the case of EDGE Olympic shows close collaboration between the client and designer. During interviews with Eric van Noord and Constantijn Berning, they both emphasize their *frequent* communication, even outside working hours.

"My relation with the client was quite close. We used to send emails in the evening. During these moments the most significant decisions were taken." (from interview with Eric van Noord, 2018)

"We had a close collaboration. [...] The main ideas for implementing circularity were proposed by the designer and me [client, Edge Technologies]." (from interview with Constantijn Berning, 2018)

The relations between the surrounding actors (the actors not part of the project team) differ for each case. Comparison of the networks shows that the integration of coordination and exchange of information for EDGE Olympic is limited, most coordination and exchange of information takes place via the client or designer. The same holds for The Green House, most coordination and exchange of information takes place via actors part of the project team. Townhall Brummen shows more coordination and exchange of information between surrounding actors (in total 4 relations exist between surrounding actors).

In sum, regarding the relations between actors, the actor networks show that most coordination and exchange of information happens between actors part of the project team or between actors part of the project team and actors outside the project team. Most frequent (thick lines) coordination and exchange of information takes place between project team members.

Already established relations

This aspect is not visualized in the actor networks. Nevertheless, it is shortly described, because the analytical framework indicates that already established relations could benefit implementation of circularity, because it could help actors to open up for innovation.

In the case of Townhall Brummen, BAM (contractor) already knew about RAU (designer) and Turntoo (circularity expert) from previous collaborations (see interview with Anne-marie van Dijk, 2018). Furthermore, the contactor mainly hired known subcontractors, except the wooden structure supplier (see interview with Joep Radermacher, 2018).

"If you want to take the next step [be innovative], you take a step into the unknown. In this situation getting the right people around the table is important, existing relations, which provide trust, are very important in taking this step." (from interview with Marijn Emanuel, 2018)

For The Green House the same actors were involved as for the Knoop redevelopment project. The actors that won the tendering process for the Knoop, were actors with whom the client had not collaborated before (see interview with Peter Eitjes, 2018). The client advised the other actors to involve the same people from each organization continuously during the whole building process, to ease interfaces and handovers in line with the vision (on circularity) of the project (see interview with Peter Eitjes, 2018).

Also in the case of EDGE Olympic, Edge Technologies (the client) already worked with people from the contractor's organization (J. P. van Eesteren), they therefore specifically asked for certain persons to work with in this new building project (see interview with Eric van Noord, 2018). Additionally, this client has long term relations with some other actors, such as with the involved specialist regarding the building services (Deerns) (Timmerman, 2018).

All three cases clearly show previously established relations with other actors (see interview with Anne-marie van Dijk, 2018; Constantijn Berning, 2018; and Jaap Bosch, 2018). The selection and choice of actors is made by the client or contractor – if the government is the client and obliged to public tendering, the contractor selects and chooses mostly *known* subcontractors.

6.1.3 Positions

As concluded from section 4. Method, the positions of the actors in the actor network relate to their centrality in the network. Centrality is defined as *"the number of connections between a node and other nodes"* (van Ruijven, 2016, p.127). This is identified by the interviews, these indicate relations between actors and the number of relations with other actors in terms of consultation, collaboration, or another form of exchange.

The contractor of Townhall Brummen takes the central position in the actor network. This actor acted as transformation agent. Most actors are positioned around this central actor. The contractor was responsible for design and build. Subcontractors were made responsible for their scope of work and the handover to other parts (see interview with Anne-marie van Dijk, 2018). The designer was formally a subcontractor of the contractor (see interview with Joep Radermacher, 2018). The project manager acted as formal intermediary between the client and project team (see interview with Joep Radermacher, 2018). As Figure 6.1 demonstrates, the project manager is positioned between the project team and the client (and external advisor).

For the case of The Green House, the project manager is positioned central. The case of The Green House clearly demonstrates that the contribution of a transformation agent is beneficial to implementation of circularity. In this case, the transformation agent was appointed by the consortium and has intrinsic motivation. Besides, as noted by other actors, this actor has the ability to motivate others and set a vision (see interview with Jaap Bosch, 2018; and Peter Eitjes, 2018). This is in line with the resources that this actor possesses: 'position in the network' and 'organization'.

For EDGE Olympic, the client is positioned as the central actor and transformation agent. The designer also has a central position (high number of relations) and several actors (reclamation experts, contractor, dismantlers, and specialists) take positions around the client and designer. The positions of the actors are located around the client and the designer.

In each case a different actor takes a central position in the actor network (see Figure 6.1). For the Townhall Brummen this is the contractor, for The Green House this is the project manager, and for EDGE Olympic this is the client. These actors act as transformation agents. As concluded from section 3. Analytical framework, this actor takes up the vision (as provided for by the client) and acts as leading in implementing circular and sustainability aspects. In addition, they engage with other actors to transfer the vision and goal and assist in bringing together the project team.

6.1.4 Influence on decision-making

Based on decisions made in the building process and involvement of certain actors, influence on decision-making is allocated for each actor in the actor network. This influence is defined as high, middle or low and depicted by the side of the node, see also section 4. Method. This is based on the interviews by identifying involvement in and influence on significant circular decisions.

In the case of Townhall Brummen, the client was involved during formal meetings only (see interview with Marijn Emanuel, 2018). The project team – including contractor, designer, and specialists – communicated more intensively and informally (see interview with Marijn Emanuel, 2018). These actors mainly influenced the decision-making. As can be seen, the contractor has highest influence on the decision-making, although decisions need to be consulted with the client. The designer and supplier(s) also influence the decision-making.

"When we decided to construct a demountable wooden structure [in the tender phase], we immediately invited a supplier to the table who would be able to deliver this." (from interview with Joep Radermacher, 2018)

The consultant, an external advisor who is hired by the municipality, mainly influences decision-making via the client. The contractor contacted the designer, because of the designer's sustainable and circular image. Already during the tender they collaborated on the design and construction of the building (see interview with Joep Radermacher, 2018). Together they looked into innovative possibilities to stimulate circularity and sustainability. For instance, they developed the idea to build the new building as an addition to the monumental villa, which would reduce energy and material use (see interview with Joep Radermacher, 2018). In addition, via the designer (RAU), the circularity expert (Turntoo, a subsidiary) joined the process. The circularity expert could exert influence via the designer (see interview with Joep Radermacher, 2018)

For The Green House the actors with high and middle influence on the decision-making are allocated in the project team, except for the subcontractor (HRBS, responsible for the herbs in the greenhouse). This actor is not part of the project organization, but has middle influence on the decision-making. The contractor (Albron) – who has highest influence on decision-making – involved this subcontractor. When the contractor joined the process the circular strategies accelerated in their concretization, probably because of his (formal) influence on the decision-making (see interview with Jaap Bosch, 2018). HRBS could influence decision-making via Albron (see interview with Jaap Bosch, 2018).

"When Albron joined, the process accelerated and they decided to focus completely on 'circularity' as the main requirement." (from interview with Jaap Bosch, 2018)

During the design and construction of The Green House, the client was only limitedly involved. The client provided the ambition of a temporary life time and stated that the components should be *taken back*, not be demolished (see interview with Peter Eitjes, 2018). At the start of this project, the development of the Knoop was already ongoing, the client offered the plot without demanding interest. This situation helped to provide a sound business case, since no rent was required, probably this resulted in parties to be more willing to participate in this innovative circular project (see interview with Peter Eitjes, 2018). The role of the transformation agent (project manager) was central in getting capable actors around the table (see interview with Peter Eitjes, 2018).

For EDGE Olympic, the client has the highest influence on decision-making. The designer and dismantler exert middle influence on the decision-making. The other actors, both from the project team and outside of the project team have little influence on the decision-making.

"For instance, we [the client, Edge Technologies] imposed how the facade and structure should been made, then we contacted others to execute the work." (from interview with Constantijn Berning, 2018)

Generally, for these cases, it can be considered that highest influence is located at the actors part of the project team. For the case of Townhall Brummen some actors outside the project team also have a relatively high influence on decision-making. A circularity expert, a supplier, the client, and a consultant exert middle influence on the decision-making, but are not part of the project team. This relatively high influence in comparison to their position could be explained by certain resources they possess. These actors have specific information & knowledge, or formal authority – in case of the client. Moreover, these cases show that the central actor (central position) oftentimes also has the highest influence on decision-making (largest node). Influence on decision-making is measured by actor's involvement in certain important rounds. In other words, the actor with the highest number of relations generally has the highest influence in the decision-making. Except for The Green House, in this case the central actor (project manager) is not the actor with the highest influence on the decision-making. For this case, the contractor has the highest influence on the decision-making.

6.2 Decision-making process

This section dives further into the decision-making process and the influence of the actors on the decision-making. Furthermore, this section aims to define what decision rounds have taken place, when they took place and what decisions were made in light of circularity. By positioning these rounds in time, the hypothesis concerning the benefit of early on decision-making regarding implementation of circularity is examined.

This section continues as follows. The building process of each case is shortly discussed, including the input and output of components from and to other buildings and locations. Then, rounds and decisions are discussed, including the involved actors and their influence on the decision-making, and the position of rounds in the phases of the building process.

6.2.1 Building process

The three case studies exist in certain contexts. The building process and its context is described in this section.

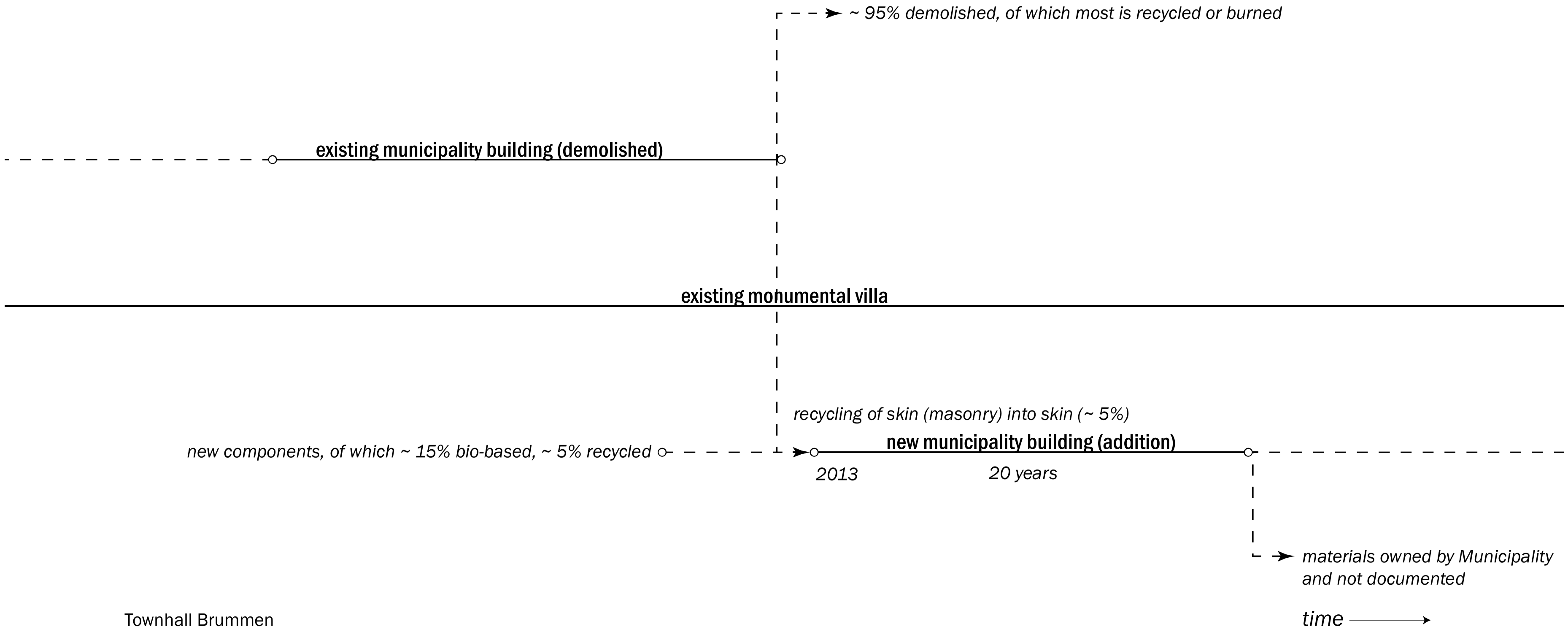
The Townhall Brummen included: 1) demolition of the existing municipality building, 2) preservation of the existing monumental villa, and 3) construction of a new municipality building as an addition to the monumental villa (van Hulst, Gemeente Brummen, & Haskoning, 2011). Unfortunately, reuse and recycling of building components of the existing building was not considered thoroughly. The existing building was almost completely demolished. Joep Radermacher explains in the interview that the building was outdated and not suitable for reuse or recycling. Figure 6.2 shows these relations between the new and existing buildings in time and depicts the amount of new, bio-based, reused, and recycled components. These percentages are estimated.

"Reuse options concerning the existing building [existing Townhall of Brummen] were not considered thoroughly. The building was outdated." (from interview with Joep Radermacher, 2018)

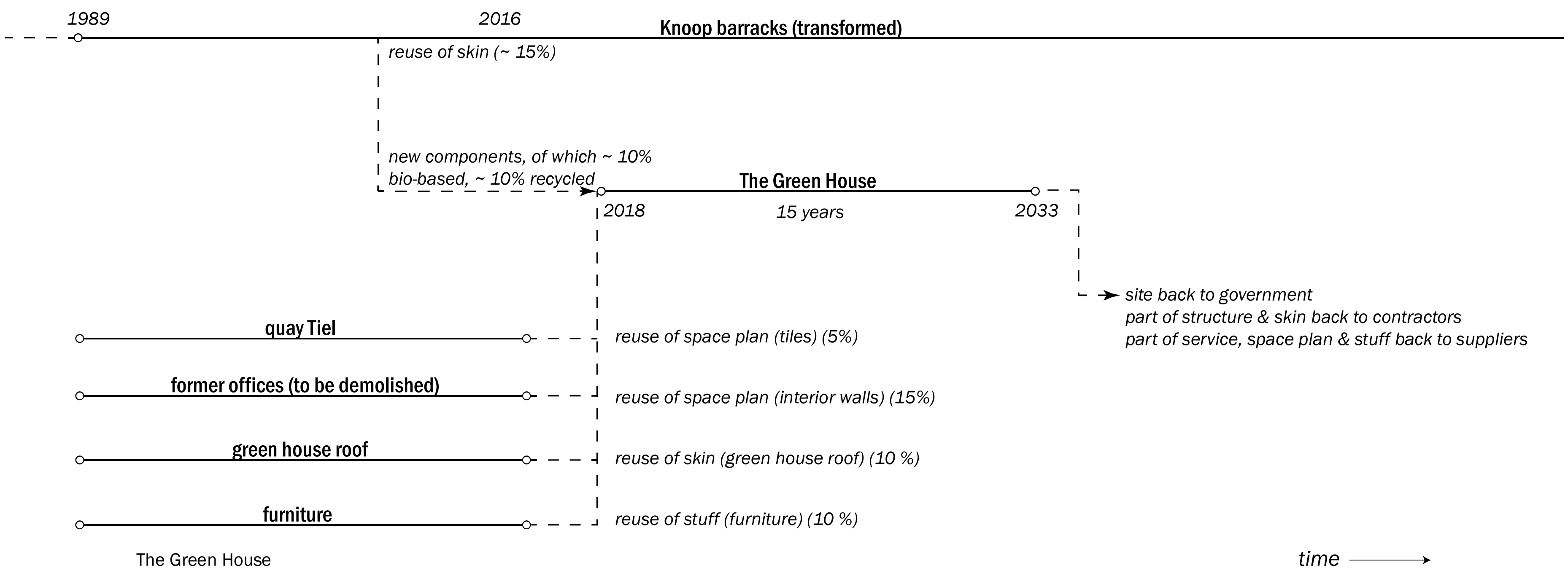
The Green House project was part of a larger development plan also including redevelopment of the Knoop. As can be seen in Figure 6.2 both building processes took place in parallel. Some materials from the Knoop building have been reused in The Green House. In addition, components have been reused from other locations. At the end of life most components will return to different involved actors.

The EDGE Olympic project concerned an existing office building. A dismantler (Beelen) executed the dismantling of the existing office building. Although the concrete structure was largely reused in its current form; the skin, service and space plan layers were almost completely dismantled (2884 ton was dismantled). From this, 97.8% was 'recycled' (see interview with Axel Hendriks, 2018). By means of enquiry at the dismantler it was found that the dismantled components (2884 ton) were, unfortunately, mainly down- or recycled, because sometimes processes for upcycling do not exist. The remaining 2.2% was burned (see interview with Axel Hendriks, 2018). As can be seen, roughly 60% of the building components consists of 'new' materials, although 55% of the existing building was reused. This is the case, because the transformed building also includes an additional floor made out of new components. The construction of this part is made of wood, it is unclear whether this is bio-based wood (dependent on the use and type of glue).

Numbers based on interview with Joep Radermacher (2018); and interview with Marijn Emanuel (2018).



Numbers based on interview with Jaap Bosch (2018); van der Wee (2018); and "The Green House opent zijn deuren" (2018).



Numbers based on interview with Axel Hendriks (2018); interview with Constantijn Berning (2018); and interview with Eric van Noord (2018).

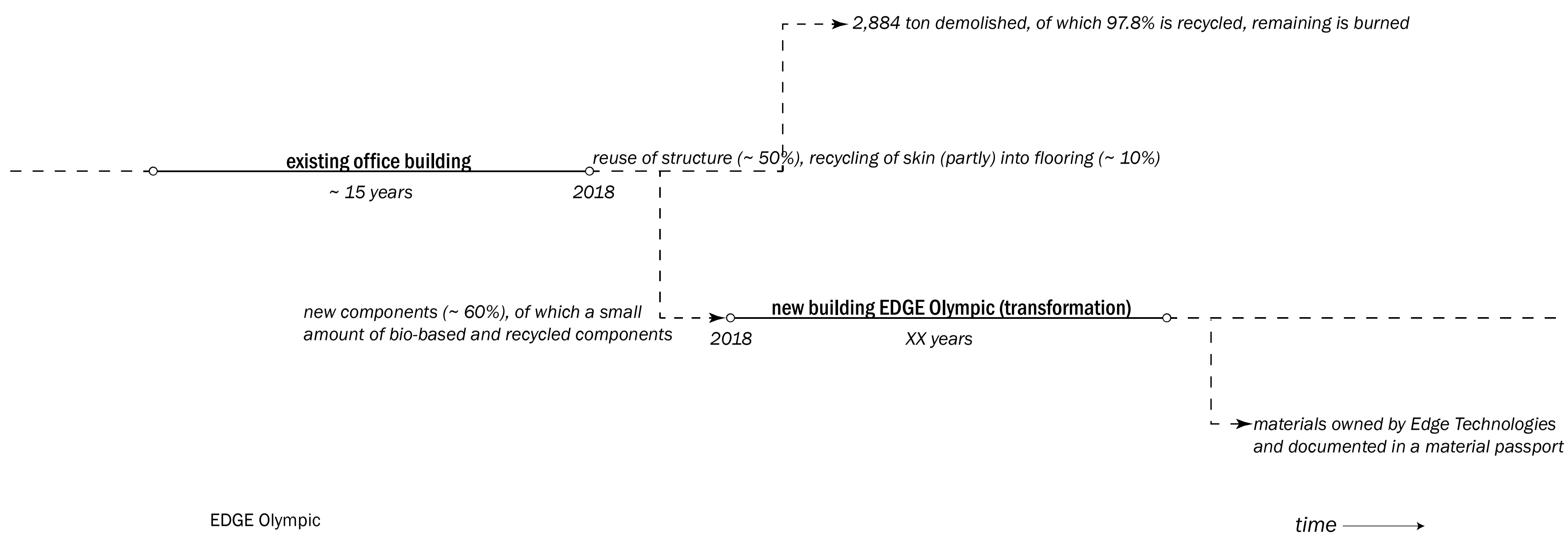


Figure 6.2 Building process for Townhall Brummen, The Green House, and EDGE Olympic respectively, including input and output of (secondhand) components and in relation to subsequent building processes.

Initiation phase

As explained, the initiation phase offers a moment to determine beginning and end of life scenarios (reduce, reuse, recycle) for the building, see also section 2. Theoretical background.

For Townhall Brummen, the municipality initiated the project by means of a public tender. Sustainability was included as one of the criteria for selection (see interview with Joep Radermacher, 2018). Besides, the client demanded a temporal building, this was translated by the project team into a demountable building with reusable components: a building as a *material bank* (see interview with Marijn Emanuel, 2018).

For The Green House the client was not involved frequently, although the client provided the project team with two requirements: the building should be temporal and demountable. Interestingly, the client provided a clear end of life scenario: at the end of life the plot should be delivered vacant, the building should be dismantled and all components and materials should be *taken back* and dealt with (see interview with Peter Eitjes, 2018; and Jaap Bosch, 2018). This clearly shows that demolition was not an option.

For EDGE Olympic the client initiated the project by proposing a vision on circularity, which included a *"demountable building with use of sustainable materials aiming to close resource loops"* (see interview with Constantijn Berning, 2018). During the whole building process the client was involved.

For all the three cases the client initiated the project by proposing a circular or sustainability related vision. The degree of involvement of the client during the process differs. In the case of Brummen and The Green House, where the government is also the client, this actor (only) initiates the project by providing a (general) vision and subsequently positions itself outside of the direct project organization (see interview with Peter Eitjes, 2018; and Anne-marie van Dijk, 2018). For these cases it holds that the client *wants* to implement circularity, the contractor *knows* how. This is in contrast to the EDGE Olympic case where the vision was set and its implementation was monitored directly by the client – although in close collaboration with the designer (see interview with Eric van Noord, 2018; and Constantijn Berning, 2018).

6.2.2 Rounds

As concluded from section 4. Method, a round is a sequence of several moments in time in which certain consultations and discussions take place to come to a decision (Klijn, van Bueren, & Koppenjan, 2000). Each round relates to a certain topic and each round leads to a decision regarding that topic (Klijn et al., 2000). A round is positioned in time where the most crucial decision(s) regarding this topic is/are made.

Based on the analytical framework, several important topics related to circularity need to be discussed to secure or aid implementation. These are related to the choice of the patterns and accompanying CSs and design strategies, see also Table 3.3 from section 3. Analytical framework. As explained, these aspects serve different ends: reduce, reuse, or recycle. It could also be the case that a case study focuses on *multiple* ends. Important to note is that these decisions could be made for beginning of life as well as for end of life scenarios. To be clear, a beginning of the building's life scenario could include use of secondhand components. In other words, the aim 'reuse' is applied by reusing an existing building or building component as input for the new building. The same holds for the end of life scenario. A different scenario, such as recycling, could be chosen for the end of life scenario.

As can be seen in Table 6.1 different patterns were discussed (and sometimes also implemented) for these cases, in relation to the beginning and end life scenarios of the buildings. The patterns relate to CSs and design strategies that have been implemented or intended to be implemented.

Table 6.1 Considered beginning and end of life scenarios for each case including patterns, CSs, and design strategies.

Townhall Brummen

Scenario	Pattern	CS	Design strategy	Implementation
Beginning of life scenarios (upfront)	Prevention & reduction [1]	De-materialization	Design for resource efficiency	Reduce dimensions structural components, lightweight construction
	Recycling (downcycling) [5]	Industrial symbiosis	Design for technical cycles	Recycled masonry from existing office
End of life scenarios (afterwards)	Repair & maintenance [2]	Functionality without ownership	Design for component extension	Product service systems, take-back of components and offering a product as a service
	Reuse & redistribution [3]	Extending product value	Design for component extension	Demountable connections, reusable measurements, standardization, separable components
	Organic feedstock [7]	Extending resource value	Design for biological cycles	Application of bio-based materials

The Green House

Scenario	Pattern	CS	Design strategy	Implementation
Beginning of life scenarios (upfront)	Prevention & reduction [1]	De-materialization	Design for resource efficiency	Reduce dimensions of structural components
	Reuse & redistribution [3]	Extending product value	Design for long-life components	Reuse of secondhand components from different locations
	Cascading & repurposing [6]	Industrial symbiosis	Design for technical cycles	Recycled finishings, i.e. recycled fishnet carpet and recycled wall finishings
End of life scenarios (afterwards)	Repair & maintenance [2]	Functionality without ownership	Design for component extension	Product service systems, take-back of components and offering a product as a service, demountable components by means of stacking separable into components, standardized grid and components
	Recycling [5]	Extending resource value	Design for technical cycles Design for biological cycles	Technical and biological nutrients, separable into homogenous materials

EDGE Olympic

Scenario	Pattern	CS	Design strategy	Implementation
Beginning of life scenarios (upfront)	Prevention & reduction [1]	Maximize material efficiency	Design for resource efficiency	Transformation of existing building
	Repair & maintenance [2]	Classic long life	Design for long-life buildings	Reuse of existing structure
	Recycling (downcycling) [5]	Extending resource value	Design for technical cycles	Recycling of façade tiles
End of life scenarios (afterwards)	Reuse & redistribution [3]	Extending product value Encourage sufficiency	Design for building life extension	Addition is designed to be demountable and separable into biological and technical nutrients, cradle-to-cradle materials
	Recycling [5]	Extending resource value	Design for technical cycles	Cradle-to-cradle materials, materials documented in a material passport

Table 6.1 shows the patterns, CSs, and design strategies that have been discussed and how these have been implemented. It is, however, of interest to determine whether these rounds have taken place early on in the building process. Therefore, Figure 6.3 visualizes the decision-making *processes* for the three cases depicted as rounds that are positioned in relation to the building process phases. This visualization seems to display a logical and neat process, but reality is oftentimes different. Sometimes decisions were made ad hoc, because of time and budget constraints (see interview with Joep Radermacher, 2018). These visualizations display time on the x-axis. On this axis, the different phases of the building process are displayed, in black the phases part of the collaboration contract are displayed. Different rounds including their involved actors are positioned in time. Black circles display actors that influence decision-making, white circles display actors that are involved in these rounds. As can be seen, each round relates to a certain topic. Some rounds take place early on in the process, thus the resulting decisions from these rounds are made early on in the process. A vertical line depicts the rounds in the *beginning* of the process. Rounds that take place on the left side of this line are considered as decisions that are made early on, as concluded from section 2. Theoretical background. As follows from this, the case study research tests the hypothesis that decisions made early on in the process are beneficial to implementation of circularity.

Below, the rounds that took place and decisions that have been made are discussed, according to the different patterns that have been identified. This is in line with the visualizations (see Figure 6.3) and schematic overview of decisions (see Table 6.1).

Prevention & reduction [1]

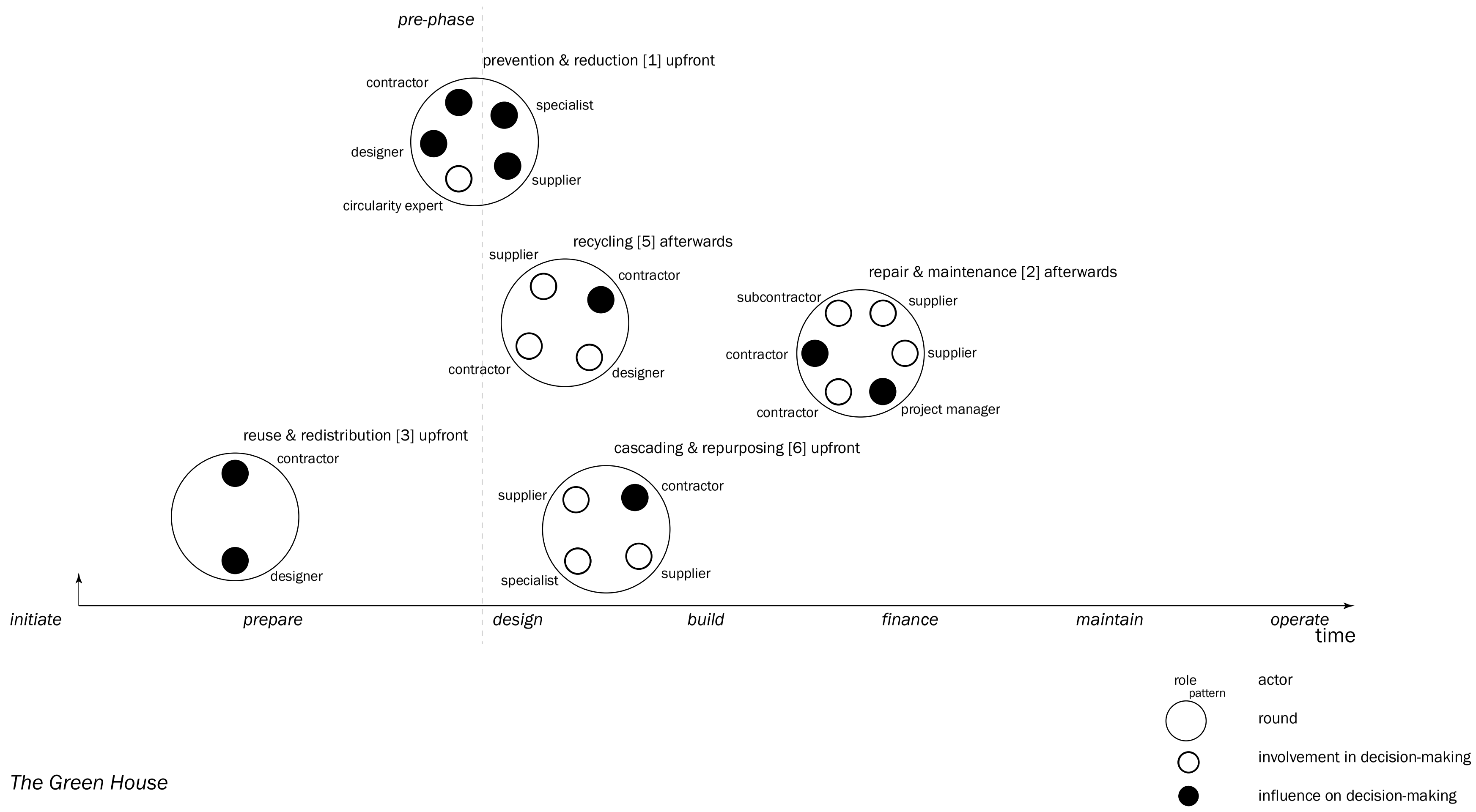
For EDGE Olympic reduction upfront was considered and decided upon in collaboration with the client and designer *early on* (see interview with Eric van Noord, 2018). The beginning of life scenario for EDGE Olympic, to use an existing office building was implemented in practice. It resulted in reuse of the structure, floor, and elevator structure (see interview with Constantijn Berning, 2018). Thereby applying 'maximize material efficiency' as a circular strategy (CS) and designing for long-life buildings as the design strategy. In addition, it can be seen that a dismantler is involved in this round. As became clear, this actor was consulted by the designer for advice on reclamation options for the existing building (see interview with Eric van Noord, 2018). Its influence and contribution to the decision-making seems, however, limited. This actor was only *limitedly* involved in other (later in the process occurring) rounds.

The Green House (contractor and designer) and Townhall Brummen (contractor, designer, and supplier) also considered 'prevention & reduction'. These cases, however, do not include transformation of an existing building. This pattern was mainly considered with respect to the CS 'de-materialization'. This included reducing dimensions of the structure or designing a light-weight structure (see interview with Jaap Bosch, 2018; and Anne-marie van Dijk, 2018). As can be seen in Figure 6.3, interestingly, both cases involved a supplier in the decision-making process to implement this pattern.

For all three cases decision-making regarding this pattern was decided upon in the beginning (during preparation or preparation and design phase) of the building process, in other words early on in the building process. The pattern was implemented in different ways, by transforming an existing building or by applying dematerialization for new components.

Repair & maintenance [2]

In case of Townhall Brummen, the decision-making process regarding this pattern (and CS 'functionality without ownership') was mainly initiated and guided by the circularity expert (Turntoo) and designer (RAU), who were also in direct contact with suppliers. The circularity expert and designer were in direct contact with the client regarding this topic – regarding



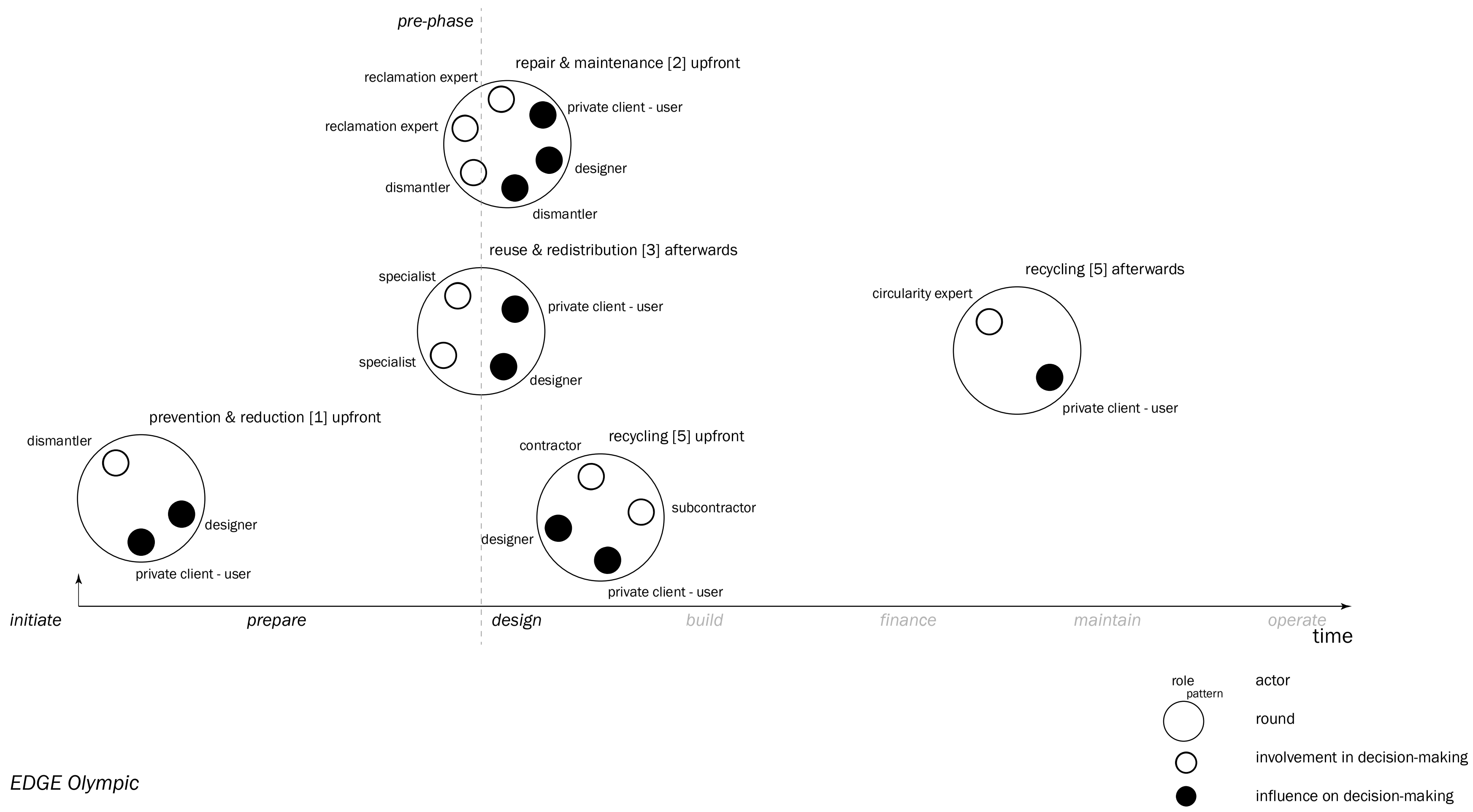
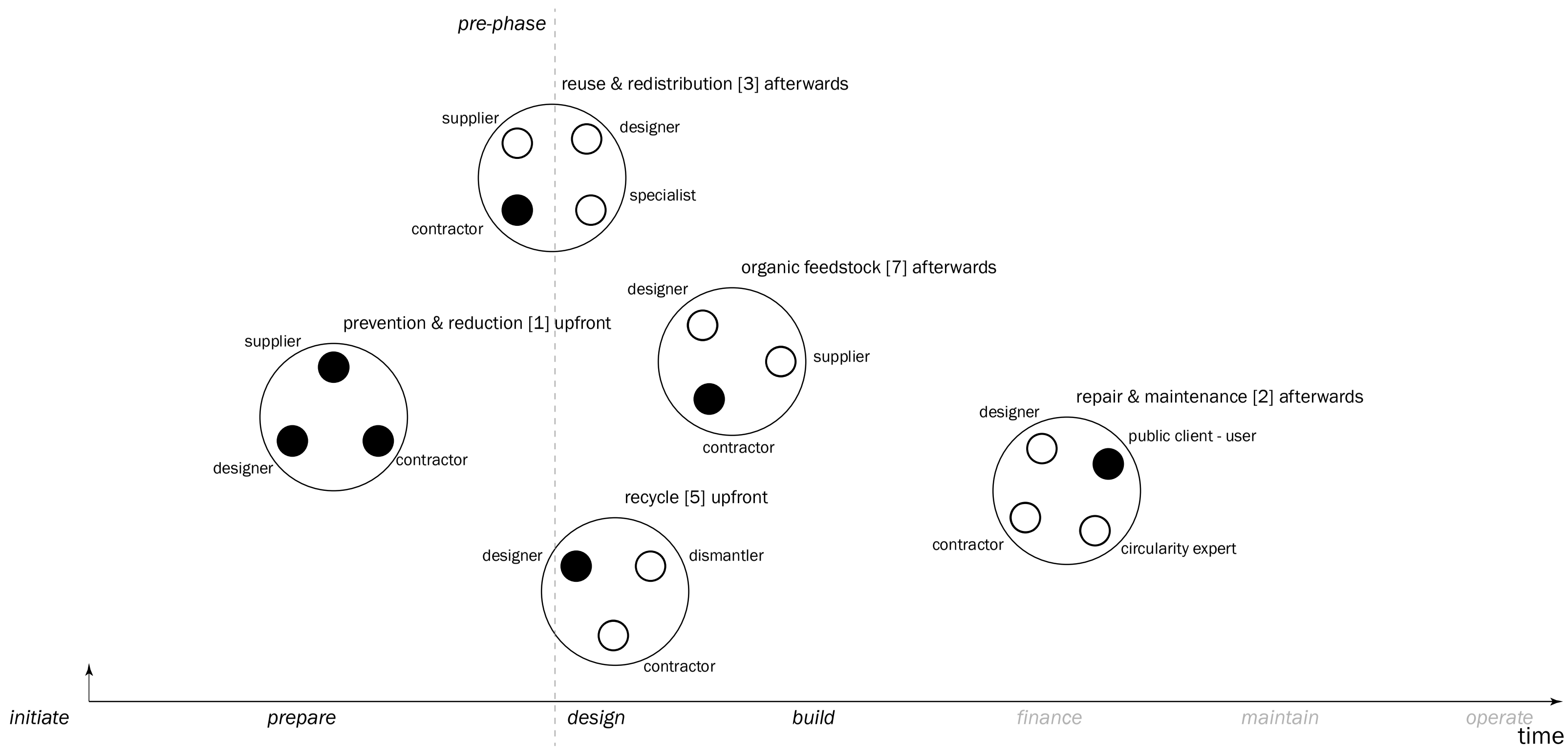
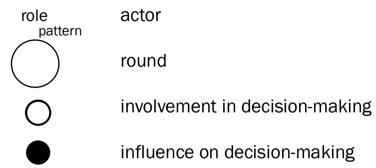


Figure 6.3 Decision-making process including involved actors, topics, and rounds positioned over time.





Townhall Brummen

other topics communication with the client took place via the project manager (see interview with Marijn Emanuel, 2018). Turntoo would help to set up a different ownership structure: the suppliers would become the owners of the different components. The circularity expert helped to materialize the CS 'functionality without ownership'. Although in the beginning Turntoo as an actor was involved in the process, later on implementation of its principles did not survive. In the end, the municipality became owner of the building, considering a depreciation rate of 40 years for this building (Gitz, 2013). The failure to implement this CS is due to financial barriers (fiscal disadvantages), uncertainty about risk coverage, and uncertainty about the function of the building after its life time. In addition, the actors, especially the municipality, appeared to have cold feet. At that time, the Turntoo business case did not have proven predecessors; it was not applied before. The newness of the concept was perceived as a risk (see interview with Joep Radermacher, 2018). Furthermore, Townhall Brummen has thus far not yet been documented in Madaster, although there is a clear connection between RAU, Turntoo and Madaster, which would ease documentation. Also, the client did not push for proper documentation of the building's components (see interview with Marijn Emanuel, 2018). If the building is documented, this would ease reuse (and recycling) in the future, even though functionality without ownership has not been implemented.

For The Green House, decision-making accelerated when contractor Albron joined the process. This contractor also became the proprietor of the building (see interview with Jaap Bosch, 2018). In this stage (build/finance phase), significant decisions regarding reuse at the end of the building's life time took place (see interview with Jaap Bosch, 2018). The designer facilitated in implementing the design strategy 'design for component extension'. For The Green House the end of life scenario was as follows: the consortium became the owner of the components and is responsible for delivering a clean site and reusing the components at the end of life. Some subcontractors and suppliers are responsible for providing functionality without ownership (CS), such as for lighting which was delivered as a product service system (see interview with Peter Eitjes, 2018; and Jaap Bosch, 2018). It must be noted that in this case, afterwards reuse was laid down at the same parties. In other words, the same parties who own the building *also* facilitate reuse, this eases reuse since no handover of components needs to take place (see interview with Peter Eitjes, 2018).

For EDGE Olympic the client and designer consulted dismantlers and reclamation experts to help decide upon reuse of the existing building structure. This round took place during the design phase of the building process. The involvement of these actors in the decision process, however, is limited (see Figure 6.3, white circles). After consultation the options for recycling, reuse and reduction of the existing building did seem limited (see interview with Eric van Noord, 2018). Although EDGE Olympic involved a non-traditional dismantler (New Horizon), they decided (for uncertain reasons) to continue the job with a more traditional dismantler (Beelen). This dismantler was responsible for dismantling the existing building (see interview with Eric van Noord, 2018). The designer took the lead in deciding on reuse options for the beginning of life. The designer looked for reuse and recycle possibilities of the existing building. This included getting in contact with specialists – such as Superuse amongst others– to get expertise regarding components that could be reused (see interview with Eric van Noord, 2018). The choices were based on energy needed to reuse or recycle components and based on the representative appearance that the building should have (as demanded by the client). Interestingly, the interior designer, who was later on involved in the process (after delivery) did not make tradeoffs in line with the 'cradle to cradle' philosophy as proposed by the client (see interview with Eric van Noord, 2018).

These cases show that 'repair & maintenance [2]' applied as a pattern to secure reuse, was implemented in different ways. The Green House and Townhall Brummen used the CS 'functionality without ownership' to make agreements on delivery of components (i.e. lighting) and determine end of life scenarios. Although, in the end this CS was not implemented in the case of

Townhall Brummen. For The Green House, the design strategy 'design for component extension' was utilized to secure demountability afterwards. EDGE Olympic involved several 'circular-related' actors to implement 'repair & maintenance [2]' upfront. In this case the CS 'classic long life' in combination with the design strategy 'design for long-life buildings' was implemented.

Reuse & redistribution [3]

For Townhall Brummen, in order to facilitate reuse of the building's components at the end of life the actors – contractor, designer, specialist, and supplier – decided to use a demountable structure and façade (design for component extension). As can be seen in Figure 6.3, the project team of Townhall Brummen already invited a supplier early on. In this round decisions were made regarding the demountability of the building, and more specifically the wooden structure. The supplier influenced the decision-making by advising to use certain dimensions, grid measurements, and connections for the structure (see interview with Joep Radermacher, 2018; and Anne-marie van Dijk, 2018). The skin of the building (façade) was also adapted to fit the design strategy. Decisions were made with respect to (reducing) the number of façade components, the type of connections, and the type of materials (see interview with Marijn Emanuel, 2018). The supplier was involved and advised regarding these topics. In addition, only one supplier was involved and responsible for the façade, this would ease take-back management of the skin at the end of life (see interview with Marijn Emanuel, 2018).

The Green House reused façade panels from the Knoop. This was initiated by the designer (see interview with Jaap Bosch, 2018). Since the redevelopment of the Knoop is part of this project and the same actors are involved (consortium and designer), demand and supply of components is easily matched. Besides, the contractor's network and relations with other contractors resulted in reuse of components from other (to be demolished) building projects (see interview with Jaap Bosch, 2018). It must be noted that in this case, the contractor actively contacted its network to find secondhand materials, since the contractor became enthusiastic about reuse of the façade panels from the Knoop (see interview with Jaap Bosch, 2018).

In the case of EDGE Olympic the client demanded the new addition to the existing building to be demountable and cradle-to-cradle certified. Thus for this case, the client decided and determined the design strategy. This decision-making process to consider scenarios for the end of life, however, took place in close collaboration between the client and the designer (see interview with Constantijn Berning, 2018). Figure 6.3 also shows involvement of two specialists in this round, they mainly provide advice. They do not influence the decision-making significantly (see interview with Constantijn Berning, 2018).

The cases implement use of secondhand building components upfront to certain extends. It seems that implementation of secondhand components in the building is facilitated by two aspects: 1) the proximity in terms of distance, and 2) the network of the involved actors. These aspects contribute to the awareness of the involved actors regarding availability of secondhand components. Additionally, reuse afterwards is mainly implemented by means of a design strategy facilitating demountability.

Refurbishment & remanufacturing [4]

This pattern was not applied in any of the cases.

Recycling [5]

In the case of Townhall Brummen it seems that the decision to recycle masonry aggregate from the existing municipality building is decided upon, because of its appearance instead of its impact on sustainability (see interview with Joep Radermacher, 2018). This was decided by the designer, contractor, and dismantler. These decisions were mainly made after the tender phase (see interview with Anne-marie van Dijk, 2018).

As explained, for The Green House most components were intended to be reused at the end of life, and would return to the consortium. Some components (from the skin and service layers) were designed for biological cycles and would be recycled at the end of life. The choice for composable materials was made in collaboration between the contractors, supplier and (interior) designer. As concluded from the previous part, and also the case for this pattern, the contractor (Albron) has the highest influence on the decision-making.

For EDGE Olympic the designer and client have the final saying in deciding upon recycling as a *beginning* of life scenario. The other involved actors in this round – the contractor and subcontractor – were mainly involved to execute the work and presumably provide some expertise, but they did not influence the decision-making. The facade tiles were recycled and applied as flooring in the new building (see interview with Eric van Noord, 2018). In addition, some of the concrete that was removed (extracted from the floor to provide for an atrium) and recycled (see interview with Eric van Noord, 2018). It must be noted, however, that these forms of extending resource value are considered downcycling. The quality of the materials is degraded, for instance, the floor tiles are cut into smaller pieces and are subject to less wear and tear.

A material passport was utilized for EDGE Olympic to share information between the involved actors and to help in securing recycling (and reuse) at the *end* of life. The client wants to use the information in the passport during the exploitation phase, to monitor the building's performance and gather data (see interview with Constantijn Berning, 2018). A circularity expert was involved to aid in choosing types of materials and providing advice on how to document and share material information (see interview with Constantijn Berning, 2018).

Unfortunately, these cases show that, oftentimes, recycled components are downcycled. For instance, the recycled concrete aggregate in case of EDGE Olympic and recycled masonry in case of Townhall Brummen are forms of downcycling, i.e. the material's value degrades.

Cascading & repurposing [6]

This pattern only has been applied to The Green House. For The Green House recycling scenarios for the beginning of the building's life time were considered. In this round the contractor, a specialist and two suppliers were involved. This resulted in implementation of recycled materials for the service, space plan, and stuff layers. For instance, ocean plastics turned into carpets tiles were applied as floor finishing (see interview with Jaap Bosch, 2018). This is an example of upgrading (Lüdeke-Freund, Gold, & Bocken, 2018). This round took place during the design and build phase of the building process.

Organic feedstock [7]

This pattern only has been applied to Townhall Brummen. For Townhall Brummen, some materials were applied based on their ability to degrade biologically at the end of life. This pattern was implemented by means of the CS 'extending resource value' and design strategy 'design for biological cycles'. This resulted in utilization of bio-based materials. This was mainly applied for the short-lived layers: space plan and stuff. The designer, contractor, and suppliers were involved in this decision-making process. This round took place during the design and build phase of the building process.

6.2.3 The different layers of the building

Table 6.2 provides an overview of CSs that have been applied (or were considered to be applied) in relation to each layer. As can be seen, 'functionality without ownership' has been applied to short-lived layers (services, space plan, and stuff) and not to long-lived layers. The same holds for 'industrial symbiosis'. This is in line with the conclusions from the analytical framework (section 3. Analytical framework) regarding the applicability of CSs to certain layers in practice. In addition, it can be seen that 'extending product value' has been applied to several layers, to long-lived layers as well as short-lived layers. The CSs 'de-materialization' and 'classic long life' only have been applied to long-lived layers for these cases.

Regarding the cases, it can be seen that none of the cases did apply CSs to the site layer. Further, EDGE Olympic did not apply any CS to the stuff layer. In consequence, no decisions regarding circularity have been made and implemented for the stuff layer (consisting of furniture and other interior objects). This is in contrast with the other two cases who did decide to choose materials based on their recycling options or made agreements on take-back management (by means of functionality without ownership) to prepare for reuse and recycling at the end of life. As can be seen, The Green House did apply a higher number of CSs to the different layers of the building than the number of CSs applied to Townhall Brummen and EDGE Olympic. Whether this means that The Green House can be considered the 'most circular' will be elaborated on in section 7. Discussion.

Table 6.2 Overview of CSs applied (or considered to be applied) for each building layer.

	Layer	Townhall Brummen	The Green House	EDGE Olympic
Long-lived layers	Site	-	-	-
	Structure	De-materialization Extending product value	Extending product value De-materialization	Maximize material efficiency Classic long life
	Skin (façade)	Extending product value	Extending product value Extending resource value	Classic long life Extending product value
Short-lived layers	Services (lighting, installations)	Functionality without ownership	Extending resource value Functionality without ownership	Encourage sufficiency
	Space plan (interior walls, finishing)	Industrial symbiosis Extending resource value	Industrial symbiosis Functionality without ownership Extending product value	Extending resource value
	Stuff (i.e. furniture)	Industrial symbiosis	Functionality without ownership Industrial symbiosis	-

6.3 Contextual factors

Contract & form of collaboration

The contract and subsequent form of collaboration provides context for the actors involvement and their influence on the decision-making process. The following forms of collaboration are applied for each case, see also Figure 6.4.

For Townhall Brummen a design & build model is utilized. In this model the contractor has a central position and coordinates between the client and designer. The client has a high influence over the process, but it not involved directly in this case (Wamelink, 2010; van Doorn, van Bueren, Chao-Duivis, de Jong, & van der Voordt, 2012). This contract provides a high degree of collaboration between design and construction phases (Kibert, 2013).

For The Green House a DBFMO model is utilized. In this case a consortium of several contractors is established. This type of collaboration usually considers the long term or whole life cycle of the building. All actors are equal in terms of influence on building process (van den Berg, 1990). This type of collaboration usually results in limited influence by the client over the process, in this case the client was not involved directly. The contractor (Albron) becomes the owner and is responsible for the operation phase. It must be noted that The Green House is part of a larger redevelopment plan (i.e. transformation of the Knoop). This was also a DBFMO project (Economic Board Utrecht & Cirkelregio Utrecht, 2018).

The EDGE Olympic project was a traditional collaboration, in which the client and designer (and some specialists) collaborated intensively during the preparation and design phase (see interview with Eric van Noord, 2018). Afterwards, when construction started, the contractor joined the process. In this case, the designer has a central position and close contact with the contractor, subcontractors, and specialists. Typically, this type of collaboration provides no incentive for the contractor to build circular (van Doorn et al., 2012).

Evaluation tools & certificates

Some sort of evaluation tool is utilized during or after the building process to measure the degree of circularity, such as GPR, EPC, or BREEAM certificates (see interview with Anne-marie van Dijk, 2018; Peter Eitjes, 2018; and Constantijn Berning, 2018). As explained by Anne-marie van Dijk during the interview, a certificate or evaluation tool offers an objective to evaluate and measure certain tradeoffs and decisions. This could facilitate circularity, since choices are grounded and based on their impact on circularity. A third independent party is sometimes involved to assess the level of circularity or sustainability. In the case of EDGE Olympic, a BREEAM assessor was hired to assess and accredit the BREAAM excellent certificate (Vos, 2018). For The Green House a circularity expert, Alba concepts, executed the evaluation (see interview with Peter Eitjes, 2018). The evaluation tool that was performed by the circularity expert for The Green House includes a section on materials and a section on connections. Information about the origin of the material (reused or new) and end of life scenarios (dump, burn, recycle) should be determined and filled in. Unfortunately, this has been filled in rather limitedly. Besides, these end of life scenarios (dump, burn, recycle) do not seem very circular. As concluded from the analytical framework (see section 3. Analytical framework), reduce, reuse or recycle is preferred in this order. For Townhall Brummen there is no certainty about application of an evaluation tool or accreditation of a certificate. The interviewees provide contradictory information on this topic (see interview with Joep Radermacher, 2018; Anne-marie van Dijk, 2018; and Marijn Emanuel, 2018).

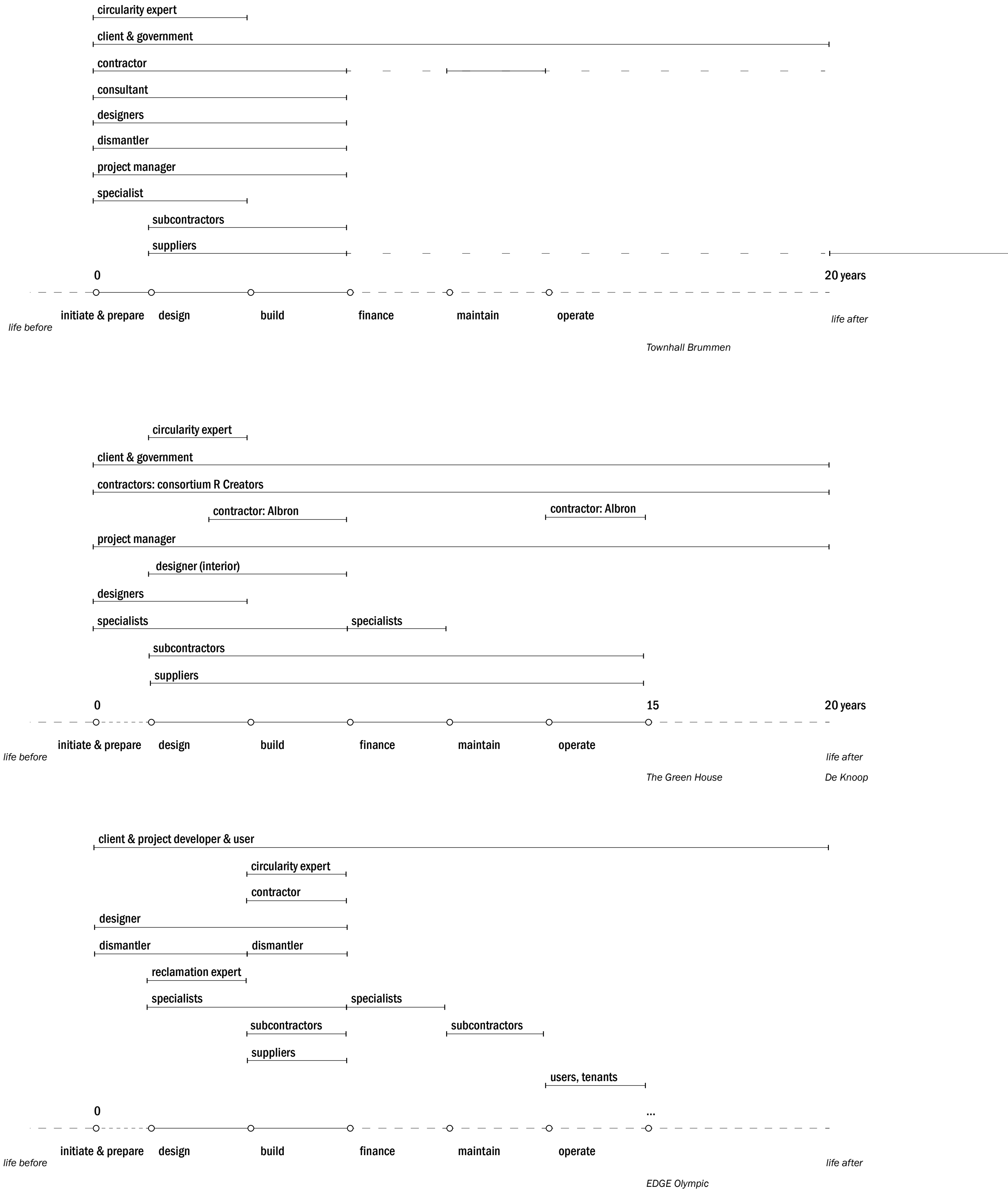


Figure 6.4 Phases in building process and responsibilities based on form of collaboration and type of contract.

Legal requirements

With respect to the three cases, the client can be characterized as a private owner-user (Edge Technologies), a public owner (not user) (Rijksvastgoedbedrijf), and a public owner-user (Municipality of Brummen). The type of client determines its interest in the project. A private owner (not user) probably has less interest in long term scenarios, than a private or public owner-user (den Heijer & van der Voordt, 2004). A public client has interest in fulfilling societal goals (den Heijer & van der Voordt, 2004). In general, the user of the building is interested in the whole life time (long term) of the building, therefore the operation and exploitation phase are also of interest. This offers the possibility to consider long-term investments, which is usually the case for circularity and sustainable building (van Doorn et al., 2012).

Government organizations are obliged to public tendering. For the Townhall Brummen and The Green House a public tender was required. The municipality invited tenders and the best proposal was selected based on ENVI-criteria (see interview with Joep Radermacher, 2018). Although, the government is subject to public tendering, it can select on the basis of sustainability criteria, amongst others. For instance, it can decline proposals that are detriment to the environment (Chao-Duivis, 2018). On the other hand, selection of actors based on previous experiences or long term relations is not possible for a public client.

Another interesting legal aspect that seems to hamper implementation of circularity is the division of ownership. Legally, a building cannot have multiple owners (see interview with Joep Radermacher, 2018; and Constantijn Berning, 2018). For implementing circularity and especially for implementation of certain CSs, some end of life scenarios advocate for multiple owners, according to the different layers of components of the building.

Market behavior

Several interviewees note the market behavior of actors – choosing the cheapest option instead of the most durable or circular option and focusing on short-term gains – as an aspect that hampers implementation of circularity (see interview with Marijn Emanuel, 2018; Joep Radermacher, 2018; and Eric van Noord, 2018). This aspect could not easily be overcome, as it is linked to the nature of the tender process and economic system in the Netherlands.

On the other hand, interviewees also note the sometimes stringent budgets provided by the client as a limiting factor. For EDGE Olympic, for instance, the designer was known to the client (Edge Technologies) by these circular ideas. Mutually, they decided to provide a 'cradle to cradle' certified building (see interview with Eric van Noord, 2018). In relation to the Circl pavilion, however, the client provided less freedom for the EDGE Olympic building. A fixed budget was provided, this hampered thorough implementation of circular principles. In addition, a representative appearance of the building was considered important. This hampered, for instance, reuse of building components on a large scale. Since this would be detrimental to the representative appearance that the building should have according to the client (see interview with Eric van Noord, 2018).

Goodwill & mindset

Some actors were not that willing to change. For The Green House, for instance, some suppliers kept acting traditionally, and did not perceive the benefits of acting not only as supplier but also as being responsible for maintenance of their products (see interview with Peter Eitjes, 2018). This is probably due to several risks they experienced, this relates mainly to difficulties to determine the residual value of components at the end of the building's life time. This risk is (partly) created by the infancy of the secondhand components market, which currently does not provide certainty on supply of secondhand components. The same holds for Townhall Brummen, the client (municipality of Brummen) would need a different mindset to apply the CS 'functionality without ownership' (see interview with Marijn Emanuel, 2018).

6.4 Conclusions

The following conclusions regarding the actor network and decision-making process can be drawn from the case study research.

Actor network

From these cases, it can be concluded that the actors part of the project team have the highest influence on decision-making. Besides, actors not part of the project team but with high or middle influence are: for Townhall Brummen the client, the consultant, a circularity expert, and a supplier; for The Green House the contractor (Ballast Nedam), and a subcontractor; and for EDGE Olympic a dismantler. These actors all are circular-related actors and/or provide circular-related resources (except for contractor Ballast Nedam).

The three cases all involved, to some extent, experts or specialists from the field of circularity (i.e. circular-related actors). For Townhall Brummen the circular-related actors part of the actor network are: a circularity expert, and a dismantler. For The Green House this is a circularity expert. And for EDGE Olympic these actors are: dismantlers, reclamation experts, a circularity expert, and investor. These circular-related actors mainly offer 'information & knowledge (and skills)' as their main resource. Regarding the actor network, the three cases show that circular-related actors are not part of the project team. The project team, for each case, consists of more traditional actors: contractor, designer, client, project manager, and specialists regarding structural engineering, building technology and services. For Townhall Brummen and The Green House the client – with 'authority (formal power)' as main resource – acts in secondary position. Regarding EDGE Olympic the client is involved directly.

Besides these actors defined as circular-related actors, the cases involved traditional actors who offered resources for the implementation of circularity. For Townhall Brummen this was a supplier (GLC), and a specialist (Brakel Atmos). For The Green House this was a subcontractor (HRBS), and suppliers (Trillux and facade supplier). And for EDGE Olympic this was a subcontractor (for the facade). These actors exert middle or little influence on decision-making.

From the three cases it can be concluded that the actor positioned central in the actor network acts as transformation agent. These are the following actors: for Townhall Brummen the contactor has the central position, for The Green House this is the project manager, and for EDGE Olympic this is the client. The identified transformation agents for each case possess the resource 'position in the network'. Additionally, as is the case for The Green House this actor also possesses the resource 'organization'. These two resources aid in getting support from others and mobilizing the actor network, a beneficial combination for a transformation agent. Regarding the influence on decision-making, these cases show that the transformation agent oftentimes also has the highest influence on decision-making. In other words, the actor with the highest number of relations generally has the highest influence in the decision-making. Except for The Green House, in this case the central actor (project manager) is not the actor with the highest influence on the decision-making. For this case, the contractor has the highest influence on the decision-making.

Actors that possess the resource 'position in the network' (contractors, and designers) utilize this resource to source for secondhand components in their network. The process of reusing secondhand components is facilitated by two aspects: 1) the proximity in terms of distance, and 2) the network of the involved actors. For the three cases both the contractors and designers possess this resource.

For the three cases it appeared that contractors also use their 'position in the network' resource to find suitable actors (subcontractors) to work with, oftentimes the contractors previously collaborated with these actors. From these case studies it remained uncertain whether already established relations are beneficial to implementation of circularity. Although long term relationships provide trust and openness to innovations, working with established relations (known actors) could exclude innovative, new players.

A high degree of coordination and exchange of information regarding circularity (knowledge) mainly occurs within the project team and between the project team and surrounding actors. The actors not part of the project team but with a high degree of coordination and exchange of information (thick lines) were as follows. For Townhall Brummen: a supplier, a circularity expert, consultant and the client. For The Green House: a supplier. And for EDGE Olympic: the contractor, a circularity expert, and a dismantler. These actors have middle or limited influence on decision-making, but they are involved in several rounds in the decision-making process.

Decision-making process

Initiation of the project provides an important moment in time to provide the basis and main goal for the circular building project. Oftentimes, for these cases, the client facilitates in initiating circularity (circular ambition). Then, other involved actors decide on suitable patterns and subsequent CSs and design strategies.

The cases show that, in early stages – initiation, preparation (and design) phase – designers, contractors or clients are involved. In case of Townhall Brummen a supplier and in case of EDGE Olympic a dismantler also early on join the decision-making. In addition, subsequently for Townhall Brummen a dismantler and a circularity expert are involved; for The Green House a circularity expert, a supplier, and a specialist are involved; and for EDGE Olympic specialists, reclamation experts, a circularity expert, and another dismantler join the process. This analysis shows that circular-related actors exert limited influence on decision-making (white circles).

Analysis of the decision-making process over time aimed to investigate the benefit of early on decision-making regarding circularity. The case study research affirms this hypothesis. It can be concluded that all rounds (and subsequent decisions) that took place early on have been implemented. And that rounds that took place later on have not all been implemented. Proper application of the pattern 'recycling [5]' in these cases is questionable, since its implementation mainly resulted in forms of downcycling. The pattern 'prevention & reduction [1]' was decided upon early on in the process for all cases. The pattern 'reuse & redistribution [3]' was also decided upon quite early on in the process for all cases. Rounds that took place *later* on in the building process *and* were implemented, mainly relate to financial or documentation aspects ('information & documentation'). Rounds regarding materials aspects ('take-back management', and 'waste handling and processing') that took place *later* on, were mainly *not* implemented thoroughly.

Some CSs have mainly been applied to short-lived layers and others mainly for long-lived layers. In addition, it can be concluded that patterns that were decided upon later in the process (i.e. rounds taking place later on), were mainly applied to short-lived layers, not to long-lived layers.

Last, contextual factors – contract & form of collaboration, evaluation tools & certificates, legal requirements, market behavior, and goodwill & mindset – seem to influence behavior of actors in the decision-making process.

Notes

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7. Discussion

This section discusses findings from the case study research in relation to the literature study. Especially deviations between the literature study and the case study research are discussed. In addition, implications and limitations of the results are provided, with the purpose of the research in mind. The purpose of this research is to evaluate current practices regarding implementation of circularity into building projects concerning the involved actors and their influence on decision-making in the building process.

7.1 Actor network

Although literature clearly identifies a list of 'circular-related' actors (besides traditional actors) that should be involved in the building process to facilitate implementation of circularity, in practice these are not (yet) always included optimally. The case study research shows that some circular-related actors were involved, but their influence remained limited. It appears that it can be questioned whether these circular-related actors should (all) be included, and if so, whether they should be included in the project team or not. Moreover, it is uncertain whether the traditionally involved actors should expand their roles so that they can provide circular-related resources themselves.

In addition, the case study research identifies a third group of actors termed 'traditional' actors with 'circular-related' resources (i.e. suppliers, subcontractors, and specialists). This group is distinguished, because of their different role in the building process in comparison to traditional and circular-related actors. These actors provide mainly 'information & knowledge' as their main circular-related resource, thereby offering in depth and specific knowledge regarding material and financial considerations concerning reducing, reusing and recycling material input and output. This shows that this third group (traditional actors with circular-related resources) has or has gained circular-related resources. If these actors have *gained* circular-related resources, this would indicate a transition process. In other words, implementation of circularity in practice is matured, because traditional actors have gained knowledge to implement circularity themselves. This means that the circular-related actors became secondary for implementing circularity.

Literature does not discuss this transition aspect or how circularity could become part of common practice in the building process. In literature, the category of circular-related actors seems to exist next to the traditional actors. The past years circular-related actors have emerged in forms of consultancy agencies, and advising and certifying companies (Kraaijenhagen, van Oppen, & Bocken, 2018). According to Gorgolewski (2008) some companies have identified circularity as an interesting business opportunity. These companies provide, for instance, consultation on how to source and find secondhand components. In the coming years these actors' practices could become obsolete, when traditional actors gain circular knowledge and resources themselves.

Obviously, universities play a role in providing 'traditional' actors (i.e. designers, contractor, specialists) with circular knowledge and resources, since sustainability is a proven essential part of the built environment. Nevertheless, as long as circularity remains in its infancy, involvement of circular-related actors will be necessary. This was demonstrated by the case studies. These cases benefitted from resources provided by circular-related actors to implement circularity. Implementation could have been more thoroughly, if these circular-related actors had become more influential. In order to properly implement their resources in the building process, they should have influence on decision-making. A position in the project team would give them an influential position.

The case study research shows the involvement of different types of clients. These are for Townhall Brummen, The Green House, and EDGE Olympic; a public owner-user, public owner not user, and a private owner-user. In other words, two public clients and one private client can be identified. As argued in the case study research (in contextual factors 'legal requirements'), these clients are involved differently and each client has a certain influence on decision-making in the building process. This is probably since they are subject to different obligations, such as public tendering for public clients. A private client is in the position to steer more directly the process and align budget and time. This is, however, only beneficial to circularity if this client utilizes this means in the right way. Thus the client should have (some) knowledge on circularity, or be able to place trust in other adequate actors. Besides, the case study research shows that the client provides a vision in a general or more specific content regarding circularity. It is unclear whether this vision should preferably be of general or of specific nature. Both the interviewees and literature provide arguments for a general as well as for a specific vision. Nevertheless, literature does indicate the benefit of co-creating such a vision (Leising, Quist, & Bocken, 2018; Bocken, de Pauw, Bakker, & van der Grinten, 2016; Kraaijenhagen et al., 2018).

Both the literature study and case study explore the benefit of already established relationships. Literature indicates that long-term relations are beneficial for implementing innovative projects, since long-term relations provide trust and openness (van der Lingen, 1998; Kraaijenhagen et al., 2018). This is in line with the results from some interviews conducted for the case study research. On the other hand, it was also argued that long term relations and choosing for known actors (i.e. subcontractors, suppliers, specialists) could exclude innovative, new players, which could be even better at implementing circularity. Considering this discussion, based on the literature study and case study research, no certainty can be provided on the influence and benefit of already established relations.

When comparing the relation of the cases' actor networks, especially the case of Townhall Brummen stands out. This case shows most relations between actors of the project team, between actors part of the project team and actors not part of the project team, and between actors both not part of the project team. In addition, this case shows relations with and early on involvement of circular-related actors and traditional actors with circular-related resources. The benefits of these relations and early on involvement for circularity seems not clear-cut. As will be later on further discussed, this did not result in 'best' implementation of circularity by means of an exemplary decision-making process.

7.2 Decision-making process

The literature study discusses the initiation phase as an important starting point for the building process. Ideally, in this phase the different ends – reduce, reuse, and recycle – should be discussed to decide upon beginning and end of life scenarios. As indicated, literature argues that reduce is the main aim (Lansink, 1979; Stahel, 2016). This should include a decision on whether to build or not to build. Although, in the case study research, it was concluded that reduce was considered as an upfront scenario for some components, this end has not been discussed with respect to the building as a whole, unfortunately. In practice, the first step would be to discuss (with the client) the necessity for building a (new) building. If this is indeed necessary, subsequent scenarios for reduce, reuse, and last recycling material input and output should be discussed.

The literature study (section 3. Analytical framework) provides a framework for categorizing patterns, circular strategies, and design strategies. From the current body of literature it became clear that there is no agreement on how to position certain circular strategies. In addition, certain concepts were depicted by different terms. Moreover, some terms such as 'circular business model' were used, that do not seem to contain the full definition of this term. A business model is a *"template between a firm's strategy and practice, allowing to examine the value proposition, value creation, delivery, and capture"* (Ritala et al., 2018, p.218). The framework (see Table 3.3 from section 3. Analytical framework) relies to a large extent on the work by Lüdeke-Freund, Gold, & Bocken (2018). Their work uses the term 'circular economy business models' or 'circular economy business model patterns'. They rely on several categorizations and frameworks made by other authors. According to Lüdeke-Freund et al. (2018, p.3) *"these frameworks propose new business models as a means to redefine how companies create and capture value while adhering to CE [circular economy] principles"*. Nevertheless, the categorization of circular economy business model patterns that follows; such as 'refurbishment & remanufacturing', or 'organic feedstock'; do not grasp the full definition of a business model. Therefore, this study uses the term 'pattern' to categorize different beginning and end of life scenarios for the building (in line with the ends: reduce, reuse, recycle). Further, the term 'circular strategies' is used to categorize strategies for dealing with different circular aspects. In that way, this study provides clarity on how to define and categorize scenarios and provides an order of choices for implementing circularity. Therefore, this study contributes to the current body of literature.

Subsequently, the case study research utilizes this framework to determine applicability and implementation of circularity. This has been done by identifying patterns that were applied or aimed to have been applied. The cases apply several patterns. Table 6.1 from section 6. Findings shows the application of patterns and accompanying circular strategies (CSs), design strategies, and practical implementations for each case. None of the cases apply the pattern 'refurbishment & remanufacturing [4]'. This pattern facilitates the end 'reuse'. This pattern requires some refurbishment and/or remanufacturing before the component can be reused. This sometimes also requires that the component is taken back to the supplier or another third party capable of executing this work (Lüdeke-Freund et al., 2018). These aspects make that this pattern is more time intensive and probably also more expensive than the other two patterns aimed at reuse ('repair & maintenance' and 'reuse & redistribution'). For these cases, in case of no maintenance and modification the other two patterns for reuse were applied. In case of maintenance and modifications, these cases did not apply pattern [4] but chose a pattern aimed at recycling.

Each case applies five patterns. This does, however, not mean that each case is equally circular. The following should be kept in mind when considering which case 'has done best'.

In the previous section (section 7.1) Townhall Brummen was discussed as a case that stands out in terms of involved actors and relations. With respect to this, the following can be discussed regarding the decision-making processes and implementation of circularly. For Townhall Brummen, the circular ambition was somewhat tempered by the client who appeared to have cold feet when implementing certain CSs. In addition, especially reuse considered as upfront scenarios could have been investigated and implemented more thoroughly. As also discussed in the interview with Joep Radermacher, reuse options regarding the existing municipality building were not considered thoroughly. The existing municipality building was demolished.

EDGE Olympic applied the pattern 'prevention & reduction' by means of transforming an existing building. Although this provides a good circular starting point, a large amount of the existing material (2884 ton) has been dismantled and mainly downcycled (see interview with Axel Hendriks, 2018). This cannot be considered as circular (following the definition used in this thesis) and shows a lack in ambition to implement circularity to its full potential. Moreover, application of recycling patterns mainly resulted in downcycling. Also, the application of CSs in relation to the different layers, shows that EDGE Olympic did not consider CSs for the stuff layer, whereas the other two cases did consider and implement CSs for each layer (except for the site layer).

In comparison to these cases, The Green House has the highest ambition regarding circularity and also implemented this most systematically (all rounds and subsequent decisions have been implemented). Furthermore, as discussed in section 2. Theoretical background, this case has also considered the multiple perspectives concerning circularity; not only the perspective materials, but also liveability was considered. Liveability has been considered in relation to the surrounding buildings and the social benefits that this building provides in an otherwise vacant plot.

Both the literature study and the case study research touch upon the aspect of the different layers of the building and the applicability of patterns, CSs, and design strategies to these layers. The literature relies on the work of de Ridder (2018) and Leising, Quist, & Bocken (2018) to indicate a difference in applicability of these strategies to short- and long-lived layers. De Ridder (2018) determines a difference in applicability regarding ends, in the sense that long-lived layers should be reused and short-lived layers should be recycled. Leising et al. (2018) indicate a difference in applicability based on circular strategies. That is, short-lived layers can best be supported by 'functionality without ownership', 'extending resource value', and 'industrial symbiosis', whereas the other circular strategies better suit long-lived layers. This is somewhat in contrast with de Ridder (2018), since according to Leising et al. (2018) these circular strategies best applicable to short-lived layers relate to reuse *and* recycling.

The case study research also relates these short- and long-lived layers to certain CSs (see Table 6.2 om section 6. Findings). It underlines that indeed a difference in applicability for short- and long-lived layers is perceived, but this is somewhat different from what was found by de Ridder (2018) and Leising et al. (2018). For long-lived layers CSs in line with the ends *reduce* and *reuse* are best applicable, and for short lived layers mainly CSs in line with the ends *reuse* and *recycle* are best applicable. In relation to the different life spans of these layers some CSs seem to be better suitable for shorter life spans (thus short-lived layers). These are mainly CSs that require (extensive) agreements regarding financial certainties, guarantees and divisions of ownership, such as for the CS 'functionality without ownership'. Whereas long-lived layers better suit CSs that do not require extensive agreements on ownership, finances, and guarantees. This would be more difficult to implement for long-lived layers, since *long term* considerations and agreements should be made.

Finally, the analysis of the decision-making process over time helped to grasp the implementation of certain patterns and analyze decisions that were made. It must be kept in mind that this analysis and accompanying visualizations provide a simplified version of reality. With this limitation in mind the following conclusions were provided. In general, early on decision-making regarding circularity benefits its implementation. Especially, decisions concerning long-lived layers should be made early on, as was concluded from the case study research. The implementation of certain circular-related decisions, such as 'take-back management' and 'information & documentation' still appears to be limited. These aspects seem to be in its infancy. The interviews touched upon these aspects. The following was argued by the interviewees:

"In practice, tack-back management at the end of life should be further developed in order to materialize in the material cycle of buildings, in financial and legal terms." (see interview with Joep Radermacher, 2018)

"The current building standards for materials and components are not suited for secondhand components." (from interview with Joep Radermacher, 2018)

"The material platform, for supply and demand of secondhand components, should be further developed." (from interview with Anne-marie van Dijk, 2018)

"It remains difficult to match demand and supply, warranties should be obtained for reused materials." (from interview with Anne-marie van Dijk, 2018)

"Evaluation tools should be developed to aid in making tradeoffs and choosing the most favorable circular solutions." (from interview with Marijn Emanuel, 2018)

"Norms for reused components need to be established." (from interview with Peter Eitjes, 2018)

These quotes show that there still exists a gap between literature and practice. Although, literature indicates these immaturities, it does not (yet) provide thorough help or guidelines on how to overcome these immaturities and support its implementation. For instance, these quotes advocate for improved establishment of a material market, to facilitate and match demand and supply of secondhand components, thereby facilitating reuse at the beginning and end of a building's life time. With respect to these aspects the literature should be enhanced. Furthermore, actors could facilitate acceleration of these aspects in practice, particularly the government could take a pivotal role in establishing these structures to facilitate circular-related decisions.

7.3 Contextual factors

Both the literature study and the case study research identify certain contextual factors. These factors seem to influence the actor's behavior in the actor network and decision-making process. The literature study identifies the following contextual aspects: contracts & forms of collaboration, evaluation tools, and goodwill & mindset. The case study research underlines these aspects and identifies some additional contextual factors, these are: legal requirements, and market behavior. Regarding the aspect 'contract & form of collaboration' differences between the literature study and case study research are experienced. In contrast to literature, were certain types of contracts and forms of collaboration are advocated with respect to circularity – i.e. DBFMO, integrated contract – some interviewees argued that the type of contract and form of collaboration is not influential for implementing circularity (see interview with Jaap Bosch, 2018; Marijn Emanuel, 2018; and Peter Eitjes, 2018). In their view, the type of contract and form of collaboration is secondary as long as actors have the right mindset. In other words, actors should be willing to cooperate and collaborate to implement circularity. Although these contextual factors came to light, it must be noted, that these aspects were not investigated and verified. The influence of these aspects on the actor network and decision-making regarding circularity falls largely outside the scope of this research and can therefore not be debated in full.

7.4 Method

As indicated in section 4. Method, the case study research relies on theory regarding actor networks and theory regarding decision-making processes. For the actor network, the work by Enserink et al. (2010), and van Ruijven (2016) is utilized to identify analytical criteria. Their work provides models for visualizing the actor network and extracting valuable information. The aspect 'previous established relations' was discussed in both the literature study and in the textual description of case study research. This aspect, however, was not included in the visualizations. The aspect 'resources' was found a valuable concept when conducting the case study research. This aspect influenced the actors' contribution to and participation in decision-making. It could have been worthwhile to depict this aspect in the actor network. This aspect, however, is not considered in the visualizations of actor networks in the literature. Although, these aspects (resources, previous established relations) are discussed by Enserink et al. (2010) and were also discussed in textual descriptions in the case study research. In the future it could be valuable to also visualize these aspects in actor network visualizations.

For the decision-making process this study relies on the work by Teisman (2000), Klijn & Koppenjan (2016), and Klijn, van Bueren, & Koppenjan (2000). In their work these authors discuss different models for visualizing decision-making processes of which the rounds model was identified as most applicable for this research. The rounds model provides a thorough basis for visualizing the decision-making process. It helps to identify and distinct between the different rounds. The content of the decision-making process was identified by relating the patterns (and CSs and design strategies) to certain rounds. These rounds were positioned on the x-axis. This helped to identify *when* decisions were made and who were involved. Moreover, it helps to position the rounds in time. This aspect in particular was considered important with respect to the hypothesis. Therefore, time is positioned on the horizontal axis and divided by the phases of the building process. Though, the rounds' topics were depicted by the patterns and the content shifted during the building process, this aspect was not measured as 'increasing' or 'decreasing'. Although this aspect was not necessary for identifying early on decision-making, in the future, it could be valuable to include the relations between rounds and the development of the decision-making process over time.

The choice for these three case studies was based on certain criteria, as provided in section 4. Method. These criteria relate to circularity and to the availability of information and documentation. With respect to circularity the criterion 'have a circular-related ambition' was considered. These criteria put greater emphasis on availability of information than on the circular ambition or the extent to which circularity has been implemented. This was necessary in order to gain sufficient information to study these cases.

Last, the choice for case study research including interviews provided a lot of valuable information. Some practical problems, however, did arise. The researcher often summarized or paraphrased the respondents to double check the correctness of this interpretation with the respondents. It appeared, however, to be difficult sometimes to keep the interviewee focused on the pre-defined questions. Second, the recording of one interview was not suitable to gather data from it. This practical problem could be mitigated by the other two interviews that were already conducted for this particular case study.

Notes

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8. Conclusions

This section provides conclusions to the research questions. This is done by relying on both the literature study and case study research as conducted for this thesis. In section 1. Introduction, the research question and sub questions were introduced:

The following research question is formulated:

"Which actors should be involved (in the beginning of the building process) to ensure circularity (implementation of circular building) throughout all phases in the building process and which actors should influence decision-making?"

The following sub questions are formulated:

"Which actors are involved in the building process of circular building projects?"

"Which actors influence decision-making on circularity?"

"What decisions on circularity are made?"

"When are decisions on circularity being made?"

With respect to the first sub question, the following is concluded:

"Which actors are involved in the building process of circular building projects?"

With respect to circular building projects, it can be concluded that 'traditional' actors, 'circular-related' actors and 'traditional' actors with 'circular-related' resources are involved. The types of circular-related actors involved in the building process, as identified in this study, are: transformation agents, circularity experts, dismantlers, reclamation experts, and a legal officer. Circular-related actors are involved in the building process by performing the role of an advisor, a consultant, or an evaluator. In addition, the case study research shows that some involved 'traditional' actors (mainly suppliers, specialists, and subcontractors) acted as 'circular-related' actors by means of their resources. It appears that resources such as 'position in the network' and 'information & knowledge (and skills)' were utilized to implemented circularity (i.e. to contribute to 'take-back management', 'acquire & procure', and 'waste handling and processing'). Unfortunately, circular-related actors and traditional actors with circular-related resources are, in most cases, not part of the project team. If these circular-related actors or traditional actors with circular-related resources become part of the project team, they will be in a better position to utilize their resources to facilitate implementation of circularity.

With respect to the second sub question, the following is concluded:

"Which actors influence decision-making on circularity?"

This study concludes that actors part of the project team (thus generally 'traditional' actors) have a higher influence on decision-making regarding circularity than actors outside of the project team. Other actors, outside of the project team, have influence on decision-making, but in an indirect way. The 'circular-related' actors predominantly exert middle or little influence on the decision-making. Although these actors are involved in most decision-making (rounds) their influence on these decisions is limited. In addition, some 'traditional' actors – which are not part of the project team – influence circular decision-making (early on) by means of their circular-related resources. This became apparent for the case of Townhall Brummen and The Green House. In these cases a supplier and a subcontractor exert middle influence on decision-making regarding implementation of circularity. Preferably, in order to ensure implementation of circularity, these actors (circular-related actors and traditional actors with circular-related resources) should be more influential in decision-making in order to enhance circularity (or circular strategies).

This study indicates the central position of a *transformation agent* in the building process. This actor has the ability to steer the circular building project and take the lead in guiding other actors towards the circular goal. The central actor (transformation agent) is not necessarily the actor with highest influence on decision-making. For each case an actor (contractor, project manager, and client) was identified that stood out in terms of ability to inspire, initiate, support and accelerate implementation of circularity. This actor acted as transformation agent. This actor could have been specifically appointed for this role or it could be the case that a traditional actor (i.e. a contractor) takes this role. In any case, this actor should have circular-related resources and knowledge to be able to guide the circular building project and mobilize others to contribute to the circular goal.

With respect to the third sub question, the following is concluded:

"What decisions on circularity are made?"

The identified framework (see Table 3.3 from section 3. Analytical framework) contributes to the body of literature regarding implementation of circularity. It shows that circularity can serve different ends (reduce, reuse, recycle), of which reduce is the preferred aim (i.e. minimizing material input and output). In accordance with these ends, certain patterns can be chosen with accompanying circular strategies (CSs) and design strategies. These patterns can be applied as beginning and as end of life scenario for the building. Accordingly, these patterns serve different resource and value strategies in line with their different ends. This framework and its strategies should materialize in the building process. Therefore, it is required that certain decisions need to be made regarding these strategies and thereby regarding the materials for circular building projects. This relates to decisions regarding the choice of patterns, CSs, and design strategies. In addition, decisions regarding the following topics are of concern: 'waste handling and processing', 'maintenance & repair', 'take-back management', 'transport and logistics', 'acquire & procure', and ‘information & documentation’ (see also Table 3.4 from section 3. Analytical framework).

Within this framework, the concept ‘design for disassembly’ is positioned as a design strategy that facilitates the end reuse. This concept was central in the previous research (Part I). As can be concluded from this framework, this study takes a broader view on circularity and also includes other ends, i.e. reduce and recycle.

Identification of these strategies in practice shows that decisions are made regarding several patterns to prepare for beginning and end of life scenarios. These patterns are considered as beginning and/or end of life scenario to facilitate reduce, reuse, or recycle. The implementation of these patterns and subsequent CS and design strategies differs. Significant circular decisions have been made regarding all patterns, except for the pattern ‘refurbishment & remanufacturing [4]’. It appears that implementation of the pattern ‘recycling [5]’ mainly resulted in downcycling (and not in upcycling). In addition, implementation of these patterns is different for long-lived and short-lived layers (see also answer to fourth sub question).

With respect to the fourth sub question, the following is concluded:

“When are decisions on circularity being made?”

Within the building process especially the initiation and preparation phase offer important moments to decide upon beginning and end of life scenarios and thereby implement circularity. In addition to preparatory activities, such as defining the program of requirements, and conducting feasibility studies, decisions should be made concerning circular-related activities. In comparison to the traditional building process, it can be argued that some additional activities need to take place or additional topics need to be discussed during the building process. These activities and topics mainly relate to the beginning and end of life scenarios of the building, such as: deciding on storage facilities for reused materials, deciding on what type of materials to acquire, deciding on how to incorporate reused materials in the design, etc.

Furthermore, with respect to the fourth sub question, section 1. Introduction also introduced the following hypothesis: *“early on decision-making on circularity in the building process benefits its implementation in practice”*. It is confirmed that early on decision-making on circularity benefits its implementation in practice. Particularly for *long-lived layers* (in comparison to short-lived layers) early on decision-making on circularity is beneficial for its implementation in practice. Later on in the building process, after the initiation and preparation (and design) phase, proper implementation of long-lived layers and subsequent CSs and design strategies is difficult. Especially concerning material aspects (‘take-back management’, and ‘waste handling and processing’) implementation benefits from decision-making before the design phase starts. For decisions regarding financial or documentation aspects (‘information & documentation’) later on decision-making is less difficult than for material aspects. The case study research shows that all rounds (and subsequent decisions) that take place early on – during initiation, preparation, or beginning of the design phase – have been implemented, and that rounds that take place later on have *not* all been implemented.

With respect to the main research question, the following is concluded:

“Which actors should be involved (in the beginning of the building process) to ensure circularity (implementation of circular building) throughout all phases in the building process and which actors should influence decision-making?”

It can be concluded that circular-related actors and traditional actors with circular related resources should be involved and be influential in decision-making in the building process of circular building projects. This study particularly demonstrates the benefit of early on involvement of the following circular-related actors: transformation agent, circularity expert, reclamation expert, dismantler, and legal officer. In addition, some 'traditional' actors with circular-related resources, which are involved early in the process, facilitate implementation of circularity, these are: a supplier, and a subcontractor. Thus, involvement of these actors early on and subsequent ability to influence or contribute to decision-making, facilitates implementation of circularity in the building process.

This is in contrast to the current state of practice. In general, traditional actors are involved and traditional actors who are part of the project team have highest influence on decision-making. These traditional actors, however, are not necessary the right actors to facilitate implementation of circularity best. In case these traditional actors lack circular-related knowledge and resources (or lack the ability to gain these resources themselves), circular-related actors and/or traditional actors with circular-related resources should be involved. Moreover, these actors should be welcomed to influence decision-making, since their resources positively contribute to implementation of circularity. In order to increase their influence on decision-making these actors should become part of the project team, or at least be taken seriously and offered room to influence decision-making. Moreover, contribution of their resources regarding circularity is facilitated, if these actors are involved early on. During the initiation and preparation phase these circular-related actors and other actors with circular-related resources should in aid deciding on the circular beginning and end of life scenarios. This means that most decisions regarding reduce, reuse, and recycle with respect to short- and (especially) long-lived layers of the buildings should be made. This results in a different building process compared to the traditional one. Since this process requires that more time is invested in the initiation and preparation phase. And the design phase should start after this phase, thus after the materials for the building have been identified. Section 9. Recommendations will elaborate further on this altered, circular building process.

9. Recommendations

From the literature study and case study research a lot of knowledge was gathered. This knowledge and subsequent analysis of the information made visible some room for improvements in practice. This section is provided to share these recommendations. These recommendations relate to the actor network and decision-making process and provide applications in practice. In addition to these recommendations for practitioners, section 9.2 provides recommendations for further research.

9.1 Recommendations for practitioners

This section provides recommendations for the actor network. This includes the actors that should be involved and their preferred role and position to ensure circularity in the building process. Further, recommendations regarding the decision-making process in relation to circularity are provided. This concerns the decisions that actors should make or look into, their preferred influence on these decisions, and the preferred timing of decision-making in the building process.

Actor network

It is concluded that, for these cases, the client *wants* to implement circularity and the contractor *knows* how. Therefore, it is recommended that in the initiation phase the client should demand to build a circular building by providing a vision which includes circular-related requirements in a general or specific manner (see Table 2.1 in section 2. Theoretical background). After this phase, the client could be part of the project team (as in case of EDGE Olympic) or act in secondary position (as the case for The Green House and Townhall Brummen). Either of the two is equally preferred as long as the client monitors the project to some extent to oversee proper implementation of the vision regarding circularity. More direct involvement of the client, however, could benefit its understanding of certain choices and tradeoffs and could help to align budget and time. In the latter case, the client should have some knowledge on circularity, that is, he or she should know what decisions facilitate circularity.

Subsequently, during preparation of the project the right parties should be participating, who *know* (have knowledge on) how to implemented circularity. This should be circular-related actors (transformation agent; circularity expert; dismantler; dealer in salvaged goods; reclamation expert; logistic partner; financier/risk analyst; insurance company; legal officer; and investor) in case the traditionally involved actors lack circular knowledge (i.e. resources). If traditional actors (client; program manager; project manager; project developer; contractor; subcontractor; specialist; designer; supplier; renter, user; consultant; and government planner, policy maker) have circular knowledge *and* the right resources to decide upon and implement circular strategies (CSs), involvement of circular-related actors is not necessary. Although, in this current rather infant stage in which circularity exists, circular-related actors have a clear benefit to aid in implementing circularity in the building and building process. Thus, involving circular-related actors as well as traditional actors with circular-related resources is of interest. It is beneficial for implementing circularity that these actors are involved, or are even part of the project team or influence decision-making in one way or another. Special attention, as appears from the case study research, should be paid to the following actors:

- Circularity experts (circular-related actor): this could be a consultant or advisor on circularity. This actor should be involved early on to gain mainly 'knowledge & information (and skills)' on implementation of circularity in general, mainly regarding choosing ends, patterns, CSs, and design strategies and on how to mitigate risks and uncertainties.
- Dismantlers (circular-related actor): involve early on to gain mainly 'money & manpower' to execute the dismantling work and 'knowledge & information (and skills)' on implementation of circularity regarding ends and design strategies. Particularly, this actor could help in identifying the probability of *reducing* and *reusing* in case of transformation of an existing building.
- Specialists (traditional actor with circular-related resources): involve early on to gain mainly 'knowledge & information (and skills)' on implementation of circularity, mainly regarding choosing CSs and design strategies. For instance, this actor could have knowledge on choosing bio-based materials as an alternative to technical nutrients for a certain building layer and securing its separability (i.e. type of connections) in order to facilitate the pattern 'organic feedstock'.
- Subcontractors (traditional actor with circular-related resources): involve early on, possibly together with a supplier to gain mainly 'money & manpower' for executing the work regarding implementation of design strategies. For example, this actor could help in realizing certain design strategies, such as demountability of the structure or skin.
- Suppliers (traditional actor with circular-related resources): involve early on to gain mainly 'money & manpower' to deliver certain components and 'knowledge & information (and skills)' on implementation of circularity, mainly regarding choosing and executing design strategies. For instance, this actor could guide in choosing and manufacturing certain components (dimensions and systems of the skin, structure, etc.) that benefit reuse.

It must be noted that for the 'traditional actor with circular-related resources' it follows that this actor should have affinity with and knowledge about circularity, or in other words be able to think along with the other actors in implementing circularity. Thus, these actors should be selected with this criterion in mind.

In addition to these recommendations regarding involvement of these abovementioned actors, a recommendation is provided about the designer and contractor. With respect to the resource ‘position in the network’ that designers and contractors oftentimes possess, it is recommended that they should utilize this resource to find reuse possibilities in their *network* and/or in *proximity* to the building location. Moreover, other actors that possess this resource should also aim to utilize it in this way.

With respect to early on decision-making, the role of a transformation agent is promising. Within the project organization a transformation agent should be identified. Or someone, with the ability to steer the circular building project and take the lead in guiding other actors towards the circular goal, should be appointed the role of transformation agent and become part of the project team. This also includes the ability to stimulate early on decision-making and securing progress.

The case study research shows that the government has different positions in the actor networks. Sometimes the government also acts as client and sometimes the government acts more distant. Nevertheless, from the literature study and case study research it appears that the government could fulfil a role in providing norms to demand circular building from market parties (more than they do now). Furthermore, the government should provide norms on reuse of secondhand components, especially in terms of providing warranties and alignment with the building code. Thus, they could fulfil a role in providing the legal possibilities to implement circularity, particularly with regards to implementation of certain CSs, that will need alternative ownership rules. For instance, it should be possible to have multiple owners of a building according to the layers or components of the building.

Decision-making process

The involved actors should rely on the topics provided in the framework (see Table 3.3 section 3. Analytical framework) for decision-making on circularity. In the preparation phase actors should decide on patterns for the beginning and end of life scenarios of the building, thereby aiming for certain ends, i.e. reduce, reuse, and recycle, in this order. Subsequently, circular strategies (CSs) and design strategies should be chosen to facilitate implementation of these ends. With this framework in mind, the following design principles should be considered in line with these ends, see Table 9.1.

Table 9.1 Practical requirements in line with preferred aims for a building project, i.e. reduce, reuse, recycle (in this order).

1) Reduce	2) Reuse	3) Recycle
1. Identify need for the building. 2. Reduce material/ component use, by deciding on size, dimensions, weight (i.e. lightweight structure).	1. Determine whether to reuse an existing building or structure (or other larger building part. 2. Investigate upfront reuse possibilities of secondhand components. 3. Design the building to be reusable (demountable) at the end of life.	1. Determine technical and biological materials (choose non-toxic materials). 2. Determine their potential to be recycled (only upcycled).

Next, in order to properly implement the sourced secondhand components, these components should be identified before the design is started or in a detailed stage. This means that, in comparison to the traditional building process, some additional rounds need to take place *before* the design phase. These rounds related to decisions regarding ‘waste handling & processing’, ‘maintenance & repair’, ‘take-back management’, ‘transport & logistics’, acquire & procure’, and ’information & documentation’ (see also Figure 3.1 and Table 3.4 from section 3. Analytical framework). In practical terms, this means that the following should be decided upon and implemented: sourcing of reused components, storage, qualification, acquire, transport, and incorporation of components and materials into the design. Thus, scenarios for upfront and afterwards reduction, reuse, and recycling of components must be considered. Other actors and especially the client should take these additional rounds into account and be open to the different appearance that secondhand components could have.

Ideally, decisions regarding circularity should be made early on to benefit its implementation. This is especially the case for implementing circularity regarding long-lived layers. Additionally, mainly for short-lived layers the CS 'functionality without ownership' (by means of leasing or buy back guarantees) is suitable, whereas for long-lived layers afterwards and upfront reuse should be dealt with via marketplaces. For the long-lived layers, 'dematerialization' and 'classic long life' are well applicable. In addition, as already indicated, the decision to reuse secondhand components upfront should be made before the design is initiated. In other words, actors should decide to set up a material inventory before they start designing. This is more efficient in terms of time and cost.

The above provided recommendations are summarized in Figure 9.1. This Figure depicts the improved building process, with respect to decision-making and actors, based on the recommendations.

9.2 Recommendations for further research

Section 7. Discussion provides discussion on the results from the literature study and case study research regarding its deviations and limitations. This provides interesting ground for further research. This section highlights recommendations for further research.

Actor network

First, further research is necessary to determine whether 'circular-related' actors and 'traditional' actors with 'circular-related' resources should be involved in the project team. Perhaps they could also be beneficial to implementation of circularity if they are involved early on in the decision-making without being part of the project team. In addition, further research is necessary to determine whether (all) circular-related actors should be involved or whether traditional actors should expand their roles and obtain 'circular-related' resources, so that they can fulfil the positions of circular-related actors.

Another interesting aspect that arose from the case study research is the different types of clients that were involved. It seems that especially the difference between a public and private client could provide certain implications for implementation of circularity. This is especially interesting in light of aspects provided as contextual factors, such as legal requirements, since public clients are subject to public tendering. Further research into the influence of public tendering on implementation of circularity could provide interesting insights and opportunities on how to further implement circularity.

Last, the aspect of already established relations was touched upon in the literature study and case study research. Both the literature study and case study research indicate that this aspect could be of influence on the actor network – selection of actors and their resources – and thereby on implementation of circularity. Generally, it is argued that long-term relations (i.e. previously established and continuing relations) provide trust between actors and openness to consider innovations (i.e. circularity). On the other hand, it is argued that choosing known actors (in other words actor with whom previous relations exist) excludes new, innovative actors (with circular-related resources) who could possibly be more beneficial to implementing circularity. The influence of this aspect should be further investigated. Furthermore, the influence of long-term relations within the building process (i.e. involve the same organizations for beginning of life as well as for end of life scenario) is also an interesting aspect for further research.

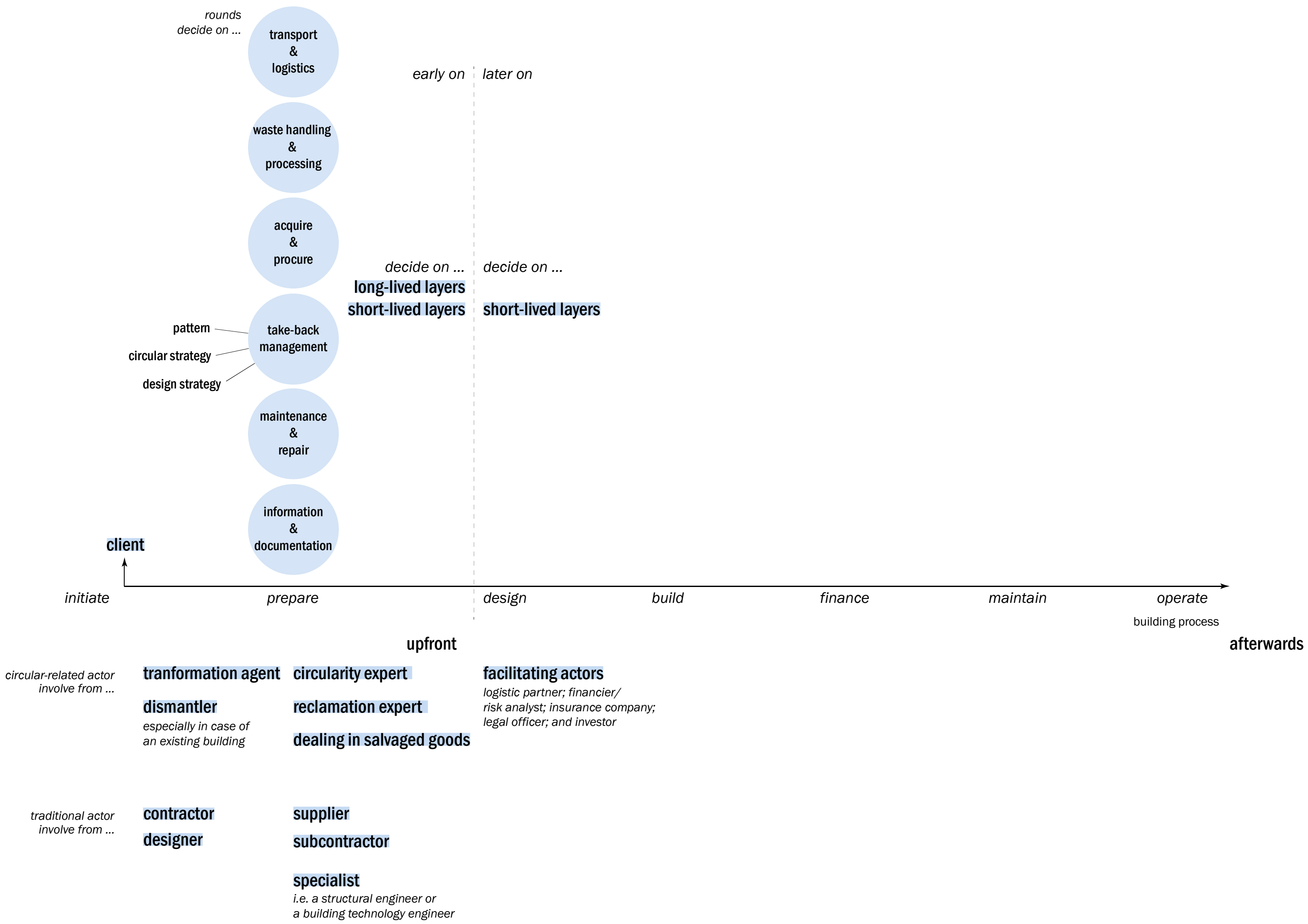

Figure 9.1 Recommended building process regarding actors and decision-making to facilitate circularity. This shows recommended decision-making including circular aspects that should be discussed in the prepare phase, these can be dealt with by means of defining patterns, circular strategies, and design strategies to be applied as upfront or afterwards scenario. This Figure shows the most significant actors that benefit circularity by means of their (circular-related) resources. Depending on the nature of the project other actors could also be relevant to involve.

Decision-making process

The analysis of the decision-making process (see section 6. Findings) shows actors who *influence* decision-making (black circles) and actors who are *involved* in rounds (white circles). The actors who influence decision-making take the final decision regarding a certain round. The actors who are involved in a certain round steer decision-making (indirectly) by their resources, for instance, by the 'information & knowledge (and skills)' that they provide. The effect of involvement in decision-making in comparison to influence on decision-making is uncertain. In addition, the benefit of engaging actors who are involved to also influence decision-making is uncertain. Further research is necessary to determine the benefit of involvement, but limited influence *and* to determine the benefit of engaging actors (who are beneficial to implementing circularity) in the actor network so that they are not only involved but also have influence.

Beside the above-mentioned gaps in the case study research or literature study, it appears that some gaps occur between theory and practice in general. Several concepts in literature regarding circularity have not (yet) matured in practice. Particularly, theory on the circular aspects ('waste handling and processing', 'maintenance & repair', 'take-back management', 'transport and logistics', 'acquire & procure', and 'information & documentation') has not been implemented in practice as the literature intends it to be. In addition, it appears that none of the strategies were applied to the 'site' layer. Further research could help to provide more thorough information on how to implement these aspects in practice. Especially, regarding the scalability of these aspects, in other words the application of these aspects to buildings of larger scale. The case study research was applied to cases of relativity small scale. Therefore, it could be that buildings of larger size experience other difficulties for implementation of circularity. Thus, further research could help to further mature circularity in theory and in practice.

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Appendix I

Interview schedule

Townhall Brummen

name	role	company	date	remark
Maartje van den Berg	advisor	Blossom	-	request declined
Ellen Hanzens	client	Municipality Brummen	-	request declined
Marijn Emanuel	designer	RAU, Madaster	21-11-2018	
Anne-Marie van Dijk	contractor	BAM	22-11-2018	
Joep Radermacher	contractor	BAM	8-11-2018	

The Green House

name	role	company	date	remark
Peter Eitjes	client	Rijksoverheid	7-11-2018	
Jaap Bosch	designer	cepezed	9-11-2018	
Rogier Joosten	project developer	R Creators	9-11-2018	sound recording poor quality

EDGE Olympic

name	role	company	date	remark
Eric van Noord	designer	Architekten Cie.	8-11-2018	
Constantijn Berning	client	EDGE Technologies	21-11-2018	
Axel Hendriks	dismantler	Beelen	10-12-2018	contact via mail
Ton Wansing	contractor	J P van Eesteren	-	request declined
Rob van Aarem	client	EDGE Technologies	-	request declined
Roshan Rampersad	client	EDGE Technologies	-	request declined

Appendix II

Interview setup

General

1. Which actors should be [/were] involved in the pre-phase to ensure circularity throughout all phases in the (design for disassembly) building process and what are their responsibilities?

Actors & relations

2. How are you and your company involved in this project?

2.1. Why are you involved in this project?

2.2. How would you position your company within this project (i.e. central)?

2.3. Was your role different in comparison to 'traditional' projects?

3. Who were involved within the project (partners)?

3.1. What were their activities and what roles did they play (both formal and informal)?

3.2. Who were involved outside of the direct project team (advisory, education team) and how?

3.3. What parties/people were essential within this project and why?

3.4. Did you already collaborate previously with certain actors?

4. During which phase was each actor involved?

5. How did you communicate?

5.1. What was the frequency of communication?

5.2. How many times did you speak to [actor]?

5.3. Which actor was central in the project communication?

Activities

6. How are you (or is your company) working on circularity within the building sector?

6.1. What activities/projects do you do around circularity?

6.2. Was this your/your company's first circular building project?

6.3. What were your main activities – both individual and at company level – within this project and during which activities you needed other parties?

7. Was the project based upon a vision/ambition? What does this vision contain?

7.1. To what extent was this vision shared by everyone/did other interpretations arise?

7.2. Which actor took the lead?

7.3. How did you realize this vision/ambition?

8. What steps were undertaken at the beginning to implement circularity?

9. Did you make use of recycled materials and secondhand? (upgraded or downgraded)

10. What preparations did you make for the end-of-life (i.e. documentation, certification)? (reuse used)

Circular strategies

11. What circular strategies (reduce, reuse, recycle) and tools were used within this project?

11.1. How did these strategies contribute to minimizing waste and reducing resource consumption?

11.2. Was this evaluated/measured?

11.3. What strategies did work and why?

11.4. What strategies did you miss?

12. What barriers did you experience for implementation of circular building & minimization of building waste?

12.1. Did you encounter risks? (liability, insurance for secondhand materials)

13. Could you describe the business model within this project?

13.1. What was different from this compared to a standard business model?

13.2. What is delivered to the client, and how?

13.3. How does this organize revenues and feasibility of the project?

Responsibilities & collaboration

14. Could you depict the responsibilities of involved actors?

14.1. And how did this contribute to circularity?

15. What did the project organization look like?

15.1. How did the division of tasks look like?

15.2. What did you do yourself and what was outsourced?

16. How did you collaborate?

16.1. What was the most innovative element in the collaboration during the project?

16.2. How did you deal with shared risks?

16.3. With whom (what parties/actors) did you collaborate intensively?

17. What was different within the contracts with partners (other than standard)?

17.1. How was the result specified (i.e. performance agreements)?

General

18. Could you name 5 significant actors that should be involved in the beginning of

the project to ensure circularity?

19. Could you name 5 activities that should be undertaken in the beginning to secure implementation of circularity?

20. Could you name 3 barriers or challenges you experienced for implementation of circularity?

21. Could you name 3 opportunities or strengths you experienced for implementation of circularity?

22. What are drivers or barriers would appear when scaling up this project?

23. What are the most important lessons for others working on the implementation of the circularity?

Appendix III

Actors

Townhall Brummen

List of actors and accompanying organizations and resource for Townhall Brummen, based on interview with Joep Radermacher (2018); interview with Marijn Emanuel (2018); interview with Anne-marie van Dijk (2018); and Wind & van Geffen (2013).

Actor	Organization	Main resource
Client, government, user	Municipality Brummen	Authority (formal power)
Project manager, contractor	BAM	Information & knowledge (and skills) Position in the network
Subcontractor (constructor wood structure)	HBC	Manpower & Money
Subcontractor (roof)	Oranjedak	Manpower & Money
Subcontractor	BSM	Manpower & Money
Subcontractor (floor)	Dycore	Manpower & Money
Subcontractor (façade)	Oskomera	Manpower & Money
Subcontractor (green roof)	Mostert de Winter	Manpower & Money
Specialist (structural engineer)	BAM	Information & knowledge (and skills)
Specialist (wood structure)	IBZ Raadgevend Ingenieursbureau	Information & knowledge (and skills)
Specialist (building technology)	Peutz	Information & knowledge (and skills)
Specialist (services)	BAM	Information & knowledge (and skills)
Specialist (roof)	Brakel Atmos	Information & knowledge (and skills)
Designer	RAU	Information & knowledge (and skills) Position in the network
Designer	Prima Interior Consultants	Information & knowledge (and skills)
Designer	Van Brakel interior	Information & knowledge (and skills)
Supplier (wood structure)	GLC	Information & knowledge (and skills) Manpower & Money
Supplier (paper desk)	Pollopak	Information & knowledge (and skills) Manpower & Money
Suppliers (electricity)	NUON	Information & knowledge (and skills) Manpower & Money
Supplier (lighting)	Philips	Information & knowledge (and skills) Manpower & Money
Supplier (elevator)	Mohringer	Information & knowledge (and skills) Manpower & Money
Consultant (external advisor)	Royal Haskoning	Information & knowledge (and skills)
Circular-related actor	**Organization**	**Main resource**
Circularity expert	Turntoo	Information & knowledge (and skills)
Circularity expert	BREEAM	Information & knowledge (and skills) Instruments
Dismantler	Enzerink	Information & knowledge (and skills) Manpower & Money

The Green House

List of actors and accompanying organizations and resource for The Green House, based on interview with Peter Eitjes (2018); interview with Jaap Bosch (2018); Crone (2018); and Wind (2018).

Actor	Organization	Main resource
Client, government	Rijksvastgoedbedrijf	Authority (formal power)
Project manager	-	Position in the network Organization
Contractor	Ballast Nedam	Information & knowledge (and skills) Position in the network
Contractor	Facilicom	Information & knowledge (and skills) Position in the network
Contractor	Strukton	Information & knowledge (and skills) Position in the network
Contractor	Albron	Information & knowledge (and skills) Position in the network
Subcontractor (food)	HRBS	Information & knowledge (and skills) Manpower & Money
Specialist (structural engineer)	Pieters Bouwtechniek	Information & knowledge (and skills)
Specialist (building technology, services)	-	Information & knowledge (and skills)
Designer	cepezed	Information & knowledge (and skills) Position in the network
Designer	Coster design	Information & knowledge (and skills)
Supplier (structure)	-	Information & knowledge (and skills) Manpower & Money
Supplier (façade)	-	Information & knowledge (and skills) Manpower & Money
Supplier (lighting)	Trilux	Information & knowledge (and skills) Manpower & Money
Government	Municipality of Utrecht	Authority (formal power)
Circular-related actor	**Organization**	**Main resource**
Circularity expert	Alba concepts	Information & knowledge (and skills)
Legal officer	Rijksvastgoedbedrijf	Information & knowledge (and skills)

EDGE Olympic

List of actors and accompanying organizations and resource for EDGE Olympic, based on interview with Eric van Noord (2018); interview with Constantijn Berning (2018); and de Architekten Cie. (2018b).

Actor	Organization	Main resource
Client, project developer, user	Edge Technologies	Manpower & Money Authority (formal power) Position in the network
Contractor	J. P. van Eesteren	Information & knowledge (and skills) Position in the network Organization
Subcontractor (flooring)	-	Manpower & Money
Subcontractor (structure)	-	Manpower & Money
Subcontractor (roofing)	-	Manpower & Money
Subcontractor (façade)	-	Manpower & Money
Specialist (building costs)	IGG	Information & knowledge (and skills)
Specialist (structural engineer)	Lievense advies en ingenieurs	Information & knowledge (and skills)
Specialist (services)	Deerns	Information & knowledge (and skills)
Designer	De Architekten Cie.	Information & knowledge (and skills) Position in the network
Designer	Concrete Architects	Information & knowledge (and skills)
Supplier	-	Information & knowledge (and skills) Manpower & Money
Renter, user	Software Improvement Group	Information & knowledge (and skills)
Renter, user	Ebbinge	(not involved in building process)
Renter, user	EVBox	(not involved in building process)
Consultant, renter, user	Epicenter	Information & knowledge (and skills)
Government	Municipality of Amsterdam	Authority (formal power)
Circular-related actor	**Organization**	**Main resource**
Circularity expert	BREEAM (C2N, DGMR)	Information & knowledge (and skills) Instruments
Dismantler	Beelen	Information & knowledge (and skills) Manpower & Money
Dismantler	New Horizon	Information & knowledge (and skills)
Reclamation expert	Superuse Studios	Information & knowledge (and skills)
Reclamation expert	Recycling companies	Information & knowledge (and skills)
Investor	-	Manpower & Money