A MODULAR FRAMEWORK FOR INTEGRATING CIRCULARITY IN SUPPLY CHAINS

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A Modular Framework for Integrating Circularity in Supply Chains

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"If it can't be reduced, reused, repaired, rebuilt, refurbished, resold, recycled or composted, then it should be restricted, redesigned or removed from production."

— Pete Seeger

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This document is part of the Management in Built Environment Master of Science graduation thesis. The research is an effort to provide a contribution to the topic of circular economy within the building industry, particularly from a supply chain perspective.

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Abstract

Managing building supply chains is significantly challenging due to its temporary nature, design to order, fragmentation and overall complexity of processes. As the built environment strives to achieve a circular domain, there is an increasing need for solutions that close product and organisational systems together with the material and information flow running through them. These flows currently 'leak' and waste materials due to classic linear approaches they have been based on for decades. Furthermore, the context of a circular supply chain is still under research, and it mainly consists of fragmented information over various topics. Therefore, this thesis explores how circular economy principles could be implemented and enhanced within the whole construction supply chain by investigating also its control environment. This thesis's scope is the circular supply chains and the information/ material flows needed throughout the process and the respective actors involved in such flows.

The modelling of a supply chain was observed as an appropriate approach to the representation of a circular supply chain environment, as it visualises in a simplified way the complex nature of supply chains. The proposed model provided insights within three levels of analysis: process, organisations and product. The process level identified the additional process phases that are needed in the reverse loops of information and materials. The organisation level elaborated on the traditional stakeholders and new circular specific stakeholders that could be introduced into these processes. Within this level traditional stakeholders were observed to adapt their operations by introducing some of the circular specific stakeholder activities internally. The third product level, investigated the control environment and the data residing within it, both provided and required data information. Identifying the data, processes and the involved actors facilitated into the design of a Modular Circular Supply Chain Model (MCSCM). In addition, the modular structure of the model enables the adaptability of any of the modules, whether this be adding or modifying modules and functionalities to suit a wide range of circular supply chain situations. The MCSCM is expected to introduce a general image of a circular supply chain environment by making this concept more tangible into nowadays society.

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Chapter 1

Introduction

Currently, the building environment has a significant impact on the project natural surroundings, leading to the necessity for new innovative and circular methods to be used during the building process (Pomponi & Moncaster, 2017). The current linear economic models appear not to be sufficiently adequate for providing a circular and sustainable environment, as such models assume that material resources will be continuously available (Storm, 2011). According to Bonviu (2014)), the approach *"take, make, waste"* is an accurate description of the linear economy notion. Starting with harvesting raw materials, which are then transformed into the needed products. Once the intended purpose of these products is served, they are declared as waste and eventually disposed (Bonviu, 2014). The built environment is considered one of the largest world waste providers, which, according to Akanbi et al. (2019), comes mainly due to the "end-of-life" products, consequently resulting in demolition. The increasingly adverse effects from this approach, which are visible for example through climate change, air pollution and growing scarcity of natural resources, have emphasised the need to decrease the footprint of the built environment of polluting emissions and waste (Dobbs, Oppenheim, Thompson, Brinkman, & Zornes, 2011; Speth & Zinn, 2008).

A circular economy (CE) challenges the notion of "take, make, waste" by reusing products and materials in multiple different life cycles. By doing so, the full economic potential of such products and materials is enabled, while minimising waste (Ellen MacArthur Foundation, McKinsey Center for Business and Environment & SUN, 2015). In addition, the notion of circular economy investigates how the product/material loops can be closed, meaning that the re-manufacturing of such products or materials is the main goal and recycling could take place in a later phase if needed (Ellen MacArthur Foundation, 2015). Consequently, the adverse effects that are momentarily provided by the linear economic models could be minimised, whilst providing benefits, such as economic growth and job creation. According to Ellen MacArthur Foundation (2015), the gross domestic product (GDP) is expected to grow by 0.8–7% by 2050. An additional 0.2–3.0% of jobs will be created, and carbon emissions are expected to be reduced by 8–70%. It should be noted that these numbers correspond to the EU level.

Since 2018, a focus has shifted on the construction industry of the Netherlands and its emissions. Currently, 95% of the materials are being recycled, and there is a 5% reduction of the total EU CO_2 emissions during construction and 35% of the total EU CO_2 during the use of the products delivered (Spijker & van der Grinten, 2014). Although it seems like the Netherlands is significantly recycling, the analysis provided by The Ministry of Infrastructure and the Environment (2016) shows that the Dutch construction industry could not be considered circular. This comes due to a significant number of these recycled materials is often used as a road base material or as filler material in industrial estates. Conversely, roughly 3-4% of these recycled materials are used in the construction industry, while primary materials are used for the other remaining 90% (Rijkswaterstaat – Water, Verkeer en Leefomgeving, 2015). This means that most of the products and materials are being down-cycled instead of being recycled within the construction industry. Moreover, the construction industry logistics sector adds to the negative contributions of CO_2 emissions (van Luik, Luijten, Molin, van Amstel, & Vrijhoef, 2019). According to Quak et al. (2011), approximately 30% of the transportation conducted in the Netherlands is related to the construction industry, whether this is the transportation of materials or other goods.

Due to the immense benefits that CE can provide, several legislations and policies are being created to support the further development of the circular concept. For example, the Netherlands strives to lower its emissions and achieve a sustainable and circular environment by 2050, with a target of 55% reduction by 2030. Therefore, research needs to be done on how these ambitions could be explicitly achieved in the construction industry and its supply chain (Municipality of Amsterdam, 2019). A potential solution is to provide proper coordination and management to the construction supply chains and their material/information flows.

1-1 Problem Statement

Managing building supply chains can be significantly challenging due to the 'two-fold' nature characterising the industry (Janné, 2018). This two-fold nature can be understood as the relationships that occur within the project and the interdependencies between various operations or the overlap of the different building phases (Dubois & Gadde, 2002). In addition, building projects can be complex, specifically when dealing with supply chains that consist of multi-actor participants. According to Ju et al. (2017), multi-actor projects tend to make decisions on project activities based on their objectives and value systems with little regard of holistic project performance. The lack of common understanding and commitment to values, such as circularity, results in a limited understanding of how behaviours of one discipline impact the related disciplines. Ultimately, this results in the underachievement of a circular project.

The complexity within building supply chains is enhanced further due to the streams of materials used in a project, which emerge from different location points (Tesselaar, 2020). Furthermore, Lundesjö (2015), adds to this complexity and the lack of standardisation due to construction projects being led by client demand for the delivery of a 'one-of-a-kind' project, leading to minimal standardisation of products and processes. In essence, the two main issues that the building industry faces are this complexity of coordinating multi-actor participation and issues regarding streams of materials and information sharing (Janné, 2018).

As aforementioned, the Dutch government strives to achieve a circular built environment by 2050. This requires the alignment of different stakeholders within the industry (Rijksoverheid, 2016). This increases the need for solutions that close product and organisational systems together with the material and information flow running through them. These flows currently 'leak' and waste materials due to classic linear approaches they have been based on for decades. The proper coordination of construction supply chain logistics (production and transport) regarding the circular requirements could lead to higher efficiency, lower costs and lower waste. Consequentially, it will create less hindrance on the surrounding environment (Tesselaar, 2020; van Luik et al., 2019; De Bes et al., 2018). This could lead to the creation of a circular supply chain, including reverse logistics management approaches, which could help the 'sealing' of material flows.

The transition from linear to circular economy within the building industry requires innovative solutions in processes and organisation structures. One way to address this is through different building ICT systems within a control environment. Such technologies could provide more efficient management and coordination of processes (Janné, 2018). However, more research is needed to evaluate what a circular control environment consists of and how it aids the creation and management of return streams of materials and information, and achieve a more circular supply chain.

The possibility of achieving a circular supply chain has grasped the attention of researchers and practitioners, noticeable by the increasing number of articles produced every year. Concerning the academic field, the research reflects on the fragmented nature of supply chains, the challenges for implementing CE and the understanding on what circular supply chains are (González-Sánchez, Settembre-Blundo, Ferrari, & García-Muiña, 2020; Adams, Osmani, Thorpe, & Thornback, 2017). most of the researches seem to focus on particular topics, like sustainable materials or circular design strategies and many more. Despite the growing body of literature on the topic, it is observed that literature on what a circular supply chain implies in regards to challenges, processes or network structures is still scarce. To achieve a circular supply chain, there is a need for a shared understanding what CSCs are and the involvement and coordination of all respective actors of supply chains such as manufacturers, logistical companies, or distribution operators (L. Zhu, Ren, Lee, & Zhang, 2017).

On the other hand, in practice different techniques are being applied to promote circular needs, such as logistic providers with dual-channel supply chains or cross-docking (González-Sánchez et al., 2020). However, these initiatives are often within company boundaries, which contradicts the requirement of CE about joint coordination of tasks and exchange of information or knowledge (Adams et al., 2017). Thus, there is a gap between the theoretical and practical side of the building industry. In response to this, the research question emerged (Section 1-3).

1-2 Thesis objective and scope

This thesis explores how circular economy principles could be implemented and enhanced within the whole construction supply chain. This thesis's scope is the circular supply chains and the information/ material flows needed throughout the process and the respective actors involved in such flows. Identifying the changes that occur to the processes and organisation networks together together with the information flows running through them is critical for clarifying the needed changes from traditional models. In addition, the identification of the control environment, could aid to clarification in practice and increase communication and coordination of circular supply chains. Therefore, the primary objective of this thesis is as follows:

"Providing a model representation of an entire circular building supply chain, facilitated by a control environment."

The focus lies on a modular circular supply chain model and the possible effect that it would have on the main stakeholders connected to it. For this objective different perspectives need to be taken into account, which will be collected from the Dutch building industry context.

1-3 Research questions

Based on the problem statement, the relevance of the research, and its objective, the following research question is formulated.

"How would a circular supply chain environment within the construction industry look like based on theoretical and practice inputs?"

Several supporting sub-questions are formulated in order to answer the main research question. These are divided into theoretical and empirical sub-questions. The former questions can be answered based on a literature review, while empirical data is needed to answer the latter questions.

Theoretical sub-questions

- *What is the nature of the current building supply chains and their management in current theory?*

  Building supply chain and their management are the main unit of analysis for this thesis, which makes it very important to identify its current nature, peculiarities and other characteristics. The concept has been extensively researched over the years in literature, which creates significant ground for further research.

- *How is the concept of circular supply chains constituted in current theory?*

  As the notion of circularity is still relatively new in the industry, its application in the general context of supply chains and the research lying within it need to be analysed to clarify this thesis. Notions like reverse loops and reverse logistics are also researched, and they compose essential elements for circular supply chains.

- *What are the main variables that allow the design of circular supply chains environment according to theory?*

  By recognising the variables through theories of strategic management areas, the circular supply chain environment becomes more tangible. It enables the analysis and frames the practices to be carried out for the circular environment.

Empirical sub-questions

- *What tools and information systems are present within the building industry, facilitating a circular control environment?*

  A desk study will first be made to answer this question to explain the different coordination and information systems are identified and described. The systems currently present in building supply chains will then analyse the type of data information residing in them. Similarly, several different circular building tools have been introduced into the building industry market. Based on a desk study research a list of criteria, a number of tools will be identified and analysed to understand their functionalities and data information residing within them.

- *How is the MCSC theoretical model perceived by organisations active in the building industry?*

  This question makes the core for the collection of primary data through a case study approach. The data is collected 1 based on interviews with professionals from case studies. It will also act as a testing mechanism for the preliminary model. It is crucial to understand different perspectives from practice to ensure this model's usability from all involved stakeholders.

Design sub-question

- *Making a design for a circular construction supply chain model.*

  Based on both theoretical and empirical inputs, a model is proposed visualising a modular circular supply chain environment, facilitated by a control environment. This design sub-question is tightly aligned to the main research question.

1-4 Societal Relevance

As the building industry has a significant impact on pollution emissions and the Netherlands strives to become a circular environment by 2050, solutions are needed more than ever. Dong et al. (2019) argue that there is a need for a model that will coordinate and motivate all involved actors into a joint effort to implement circularity in supply chains. The model can provide such motivations as visibility is enhanced across organisations. Visibility within supply chains is considered a critical capability for improving decision-making moments and reducing supply chain disruptions (Barratt & Oke, 2007). In addition, a supply chain model like MCSCM, could aid public and private parties in reaching their goal of creating a circular supply chain environment. The MCSCM is an output from theoretical and practice inputs, which helps bring together literature and practice closer.

1-5 Scientific Relevance

The possibility of achieving a circular environment has captured the attention of not only stakeholders but also researchers, and a significant number of articles have been published

(González-Sánchez et al., 2020). *"Journal of Cleaner Production", "Sustainability"* and *"Resources"* for example published approximately 50 papers related to the concept of circular economy in general. Although, the concept of building supply chain management has been well established within literature, further research is needed to understand how supply chains can implement the principles of CE. The majority of publications that are related to circular supply chains can be mainly found in journals such as *"Sustainability"* and *"Journal of Cleaner Production"*, which have been published in 2019. However, the current research has mainly focused on describing and formulating a general definition about CE, but little research is being done on its implementation.

Building supply chains are crucial element for the implementation CE as a joint effort is required between upstream and downstream actors, for environmental and managerial objectives to be achieved (Masi, Day, & Godsell, 2017; Q. Zhu, Geng, & Lai, 2010). In response to this, the research focuses on demystifying collaboration, process and control environment requirements for the integration of circularity in supply chains. The way that this research is conducted and the synthesis to a circular supply chain model are based on both theoretical and practical inputs. Although the research is based on existing literature and theories, the output adds to the knowledge relevant to circular supply chains.

1-6 Thesis outline

The introduction chapter has explained the background of the research and provided the context together with its objectives. The research design and the approach to achieve this thesis's primary purpose will be elaborated in Chapter 2. This chapter elaborates on the methodological approach, strategy and the techniques that the research followed.

The theoretical basis of the research is put forward. In Chapter 3, some background is provided on the nature of building industry, its supply chain context and the general circularity concept. Then, the concept of circular supply chain is framed which commences Chapter 4. The analytical framework synthesises the theoretical background into four main environments and corresponding analysis variables. The information derived will provide the first information for designing the proposed model, which is crucial for this research and will act as the testing mechanism during the empirical analysis.

The empirical part of the thesis starts with identifying systems and tools that the current built environment market specifically concerning the Dutch building market (Chapter 5. These are considered in the research as secondary sources — which act as the first testing ground against theory. The information derived by this test will be used as the first input for the model. Next, Chapter 6 elaborates the case selected based on an established criterion in the research design chapter. The empirical findings from the case study are analysed, compared and interpreted. The preliminary model derived by the theoretical model is then be further tested against the case study, and based on interviews with corresponding professionals, their perceptions on the model will be collected. Lastly, the research synthesis consists of Chapter 7, in which the final proposed model is introduced through three levels of analysis: (i) process, (ii) organisation and (iii) product. Then the model is tested against a real-world case as a verification mechanism. The synthesis and overall thesis ends by addressing the main research question and its sub-questions, limitations and directions for further research are indicated.

Chapter 2

Research Design & Method

The objective of this thesis is to demystify the concept of circular economy within supply chains with the ultimate goal of providing a visualisation of a modular circular supply chain model. This chapter provides an overview of the research design and methodology of the thesis, including the research approach (Section 2-1), research structure (Section 2-2) and justification of the approach (Section 2-3).

2-1 Research approach

As the thesis focuses on understanding and researching the concept of circular supply chains in the building industry, obtaining insights into the research field from different perspectives is necessary. Therefore, the research follows qualitative methodologies, which seek to explain and provide conclusions which account to specific cases. As a result, the research will attempt to provide results that are qualitative by nature, explanatory and bounded by its context (Leedy & Ormrod, 2001). Therefore, the thesis has four characteristics: (i) explanatory, (ii) interpretative and (iii) descriptive, (iv) exploratory. First, it is explanatory as it identifies what circular supply chains and control centres are and how they are currently applied in the construction industry. Secondly, it is interpretative as it develops a model of a circular supply chain facilitated by the control centre once insights have been collected on the concept. Next, it is descriptive as it attempts to understand the difference of processes in a circular economy from the traditional ones, information, data, relationships and organisations in construction supply chains. Lastly, it is exploratory in the way that it proposes a model that can be further developed and used by different actors in the construction sector.

The notion of circularity within the building industry has gained moment in the research field in the past years. Therefore, the different theories are collected by forming a analytical framework which is tested through empirical data. In response to these characteristics and the research questions in Section 1-3, the methods used in this research correspond to a qualitative research methods, as it makes use of techniques, such as interviews and expert consultations to gather the information (Leedy & Ormrod, 2001). The findings derived from the analysis will then be conveyed on the basis of words, narratives and quotations. This type of methodology is seen as most suitable for this type of research as it allows testing and validating theories, assumptions or generalisations within the real life context (Robson, 2002).

To acquire knowledge there are two line of reasoning approaches that could be used, namely inductive and deductive reasoning (Hyde, 2000). As the research is a theory testing process, the thesis follows a deductive reasoning which commences with the established analytical framework and seeks to verify the theory to the certain circumstances. The deductive approach starts by reviewing general theories regarding circular supply chains. These theories are synthesised into an analytical model which is then used in the empirical analysis, consisting of secondary sources retrieved through a desk study and primary sources retrieved from a case study approach. According to Yin (1984) a deductive approach to a case study enhances the validity of the problem at hand when cases conform to theory; or can act as an opportunity to refine theory when cases disconform to theory.

2-2 Structure of the research

2-2-1 Part I: Theoretical basis

The first part of the thesis starts by conducting a literature review on the background of the building industry context (Chapter 3). In addition, the implementation of circularity within supply chains will be investigated. This background assisted in framing a general understanding what circular supply chains are. Once the theoretical background is finished, the analytical framework is introduced (Chapter 4). Within this framework circular supply chains are further researched, by deducting the variables of analysis that are considered to theoretically enable circular supply chains and provide the initial ground for the design of the model. The analysis variables will enable the theories to be tested during the empirical analysis.

2-2-2 Part II: Empirical analysis

In this section the empirical analysis methodology will be described. This empirical data will serve as the testing mechanism of the theoretical basis. For this to happen, the analysis units need to be defined, then the case selection and its list of criteria is described. The section follows by identifying the data sources used in this thesis and how this data is collected and analysed.

Unit of analysis

The main unit of analysis in this thesis is the *focal company* in supply chain within the building industry, applying circular strategies. In building projects this focal company represents the different organisation types that make up the supply chain. The organisation types will be the basis when categorising the selected cases, including the strategic arrangements and their influence on decision-making within the supply chain activities.

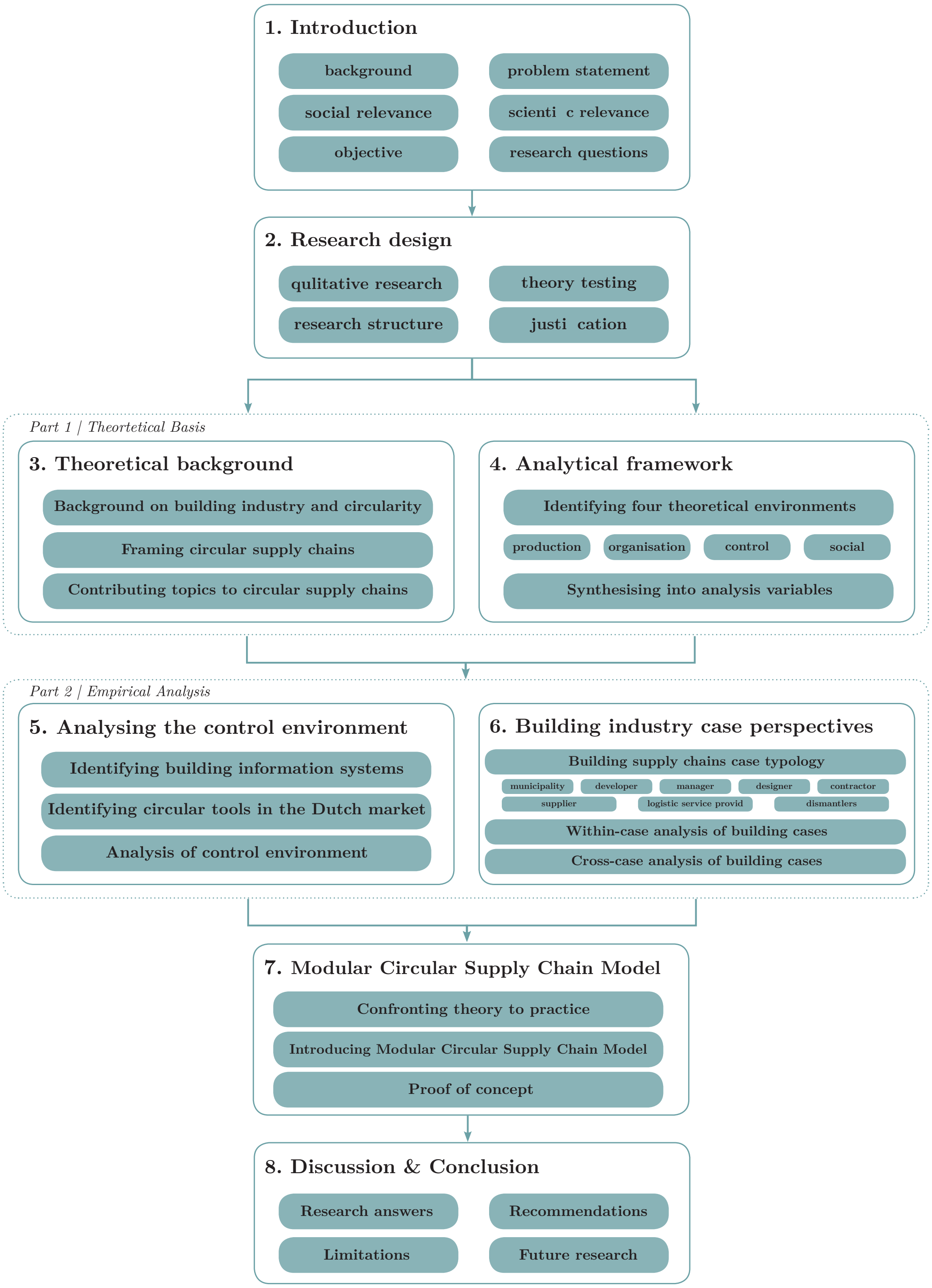

Figure 2-1: Thesis structure

Case selection

For the empirical analysis cases are selected from the Dutch context. Another critical characteristic in the selection of the cases is whether the cases are already incorporating circular principles in the development of their projects. Furthermore, in order to select the most appropriate cases, which will provide significant contribution to the evaluation of the proposed analytical model, a set of criteria is formulated:

Table 2-1: Case study selection criteria

	Case selection criteria
(i)	Relevant to the Dutch building sector
(ii)	Have interest and claim to support circular building
(iii)	Supply chain organisational functions cover different phases of the supply chain
(iv)	Circular applications are publicly accessible
(v)	Willing to cooperate and share documents
(vi)	Involved in circular building projects

The cases were first filtered not only based on their location (the Dutch context) but also through publications and articles in which circular building example projects were provided. Based on these indications the involved organisations types in those supply chains were mapped. The aforementioned criteria was used to measure the compliance of each potential case, from which most complying cases were chosen. For general usability purposes of the model, it was chosen to not only investigate one specific building project and its supply chain but rather a set of organisational building types that oversee different phases of the supply chain. This results, in the cases not comprising one specific supply chain, but still collectively covering all phases of the supply chain. In addition, most of the investigated cases have collaborated in past supply chains. The selection of these cases will be further explained in Chapter 6.

Data sources

The data sources used in this thesis contain two main types of sources: primary and secondary. Primary data sources refer to the data sources collected within the case studies. On the other hand, the secondary data refers to the information derived through external documentation, such as journals, internet sources, or news articles. In this case these sources are used to identify information systems and current circular building tools used in the construction supply chain context.

Data collection

According to Yin (1984), there are three main data types of evidence used while conducting a qualitative research: interviews, observations and documentations. By using multiple data sources it is argued that it will result in increased reliability of the research, while the use of multiple data collection methods is thought to help sustain the objective of this thesis. Therefore, this research heavily focused in collecting data based on both documentations and interviews.

The data provided from the interviews can be collected through three different interviewing types: (i) open, (ii) semi-structured and (iii) fully structured interviews. The latter is mainly used when the researcher has complete knowledge and the collected data is expected to deepen the knowledge on the topic, based on a predetermined list of questions (Turner III & Daniel, 2010). On the other hand, the open interview type has a significant exploratory nature on a topic researched (DiCicco-Bloom & Crabtree, 2006). This interview type follows a free-flowing conversation and is not based on specific questions, which may encourage biased information. Lastly, a semi-structure interview type is a mixture between the two aforementioned types. Instead of a full list of questions, a set of themes act as guidelines for the conversation, whilst maintaining an exploitative nature on the perspectives of the interviewee. The guiding themes ensure that the needed data is gathered whilst mitigating the risk of biased answers.

As the concept of circular supply chains is not yet established in literature and practice, the semi-structured interview type is considered as most favourable for this thesis. An interview protocol was established, where main themes were determined as most important for the capturing of information, see Appendix B-1.

Data Analysis

The analysis of data started by first transcribing the interview recordings, which then underwent an coding process, based on the process of Williams & Moser (2019). The coding process went through three main phases as seen in Figure 2-2, open, axial and selective coding. In the first phase, the interview is done based on the quotations within the transcripts, where the main findings are highlighted. For this part of the process Atlas TI, a qualitative coding software was used for storing all the transcribed and coded, helping in the reduction of data. Next, the axial coding process links the open codes are further categorised into the analysis variables, originating from the analytical model. The last phase, selective coding again links the axial codes to the four environments of theory.

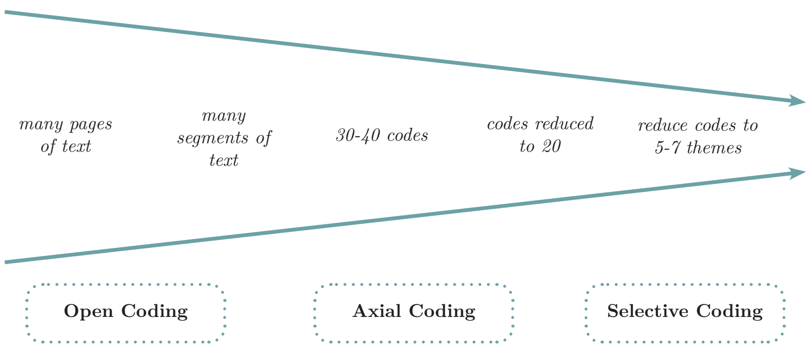

Figure 2-2: Overview of coding process: Open, Axial and Selective Coding (retrieved from Williams & Moser, 2019, p.47)

An example of this coding process is provided in Figure 2-3. The purpose of this process, is to deduct the most crucial information from many pages of interview data, by advancing the research process (Williams & Moser, 2019). Lastly, the data analysis was further built on with documentation respective to the organisation representative. A full overview of the coding list can be found in Appendix B-2.

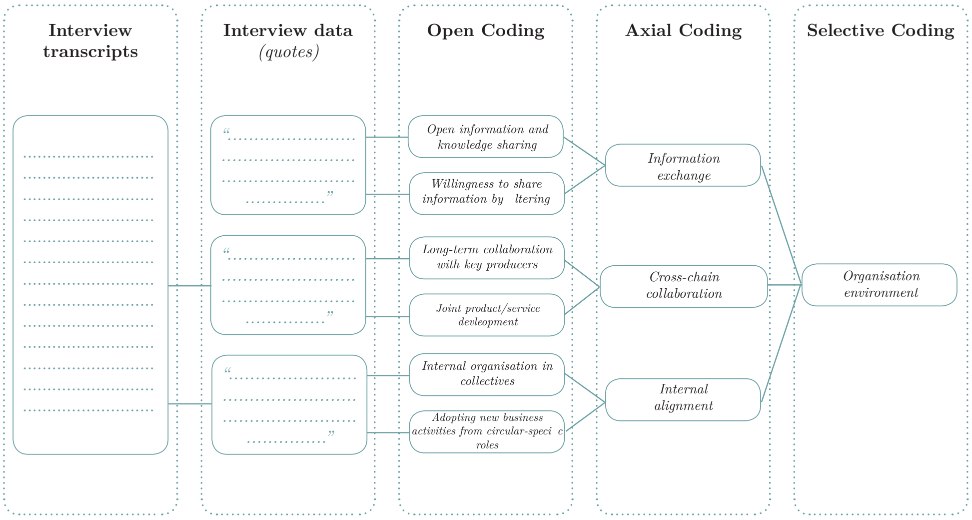

Figure 2-3: Example of the coding process

Case Study Analysis

Based on the data analysis the case study was further analysed by means of within-case and cross-case analyses. The within case analysis refer to the comparisons identified between different organisation types that held the same function. While, the cross-case analysis refer to the comparisons of the findings between different functions of organisation types. In order to increase comparability the analyses have been conducted in a similar way.

2-2-3 Part III: Synthesis

This thesis adopts the systematic approach of supply chain modelling for the purpose of providing a clear overview of the structure and functioning of circular construction supply chains by combining supply chain management with the circularity and control centre concept. In general the action of modelling represents one of the cognitive activities of a topic, which includes the development of a model to be used to conduct investigations, and provision of results or recommendations on its quality to the problem at hand (Ivanov, Tsipoulanidis, Schönberger, et al., 2017). Modelling techniques are often used to abstractly represent a complex process or entity in a simplified way. In the case of this thesis two concepts control centres and circularity are taken into consideration, which are ambiguous concepts and not formally established in construction supply chain management. Therefore, it is important to provide a clear identification of what circular supply chain environment facilitated by a control centre means.

For the modelling approach, graph-based models are evaluated as an interesting technique for the development of the analytical model phase. According to Papadonikolaki et al. (2015), this technique allows to represent complex models by simultaneously offering flexibility for the modelling environment. The complexity is created due to the different levels that this model will address: (i) process, (ii) product and (iii) organisational models. The thesis synthesises these levels into one multi-model graph where insights from both theoretical and primary/secondary empirical sources are used for the design of the proposed model. It should be noted that proposed model underwent an iterative process. The initial version was produced based on the theoretical basis, which then was tested with the empirical analysis to find relationships between theory and practice. Once this confrontation is finished, MCSC model was developed, including the identified relationships.

To verify and validate the proposed model, a test project case study is used. During the interviews with the different focal company representatives, different project cases were mentioned. These project cases were taken into consideration and based on the documentation available and their claim to be circular building projects, one was chosen to test the MCSC model, in Section 7-3.

2-3 Justification of the research approach

Validity refers to the truthful representation of the concepts that has been investigated throughout this thesis. As this research relies on qualitative methods, the validity refers to the information richness gathered by the selected cases, rather the sample size (Emory & Cooper, 1991; Patton 2002). In this thesis, the concept of circular supply chain and control centres was first investigated through a body of theory, which resulted in the main components to be addressed when creating the modular circular supply chain model. Next, the preliminary concept of MCSCM is explored by multiple case studies within the building industry context. The aim is to increase the richness of information into the concepts, indirectly contributing to increase validity internally and externally. Internal validity refers to the casual relationships that emerge between the research variables, hence the use of different analysis techniques through primary and secondary data sources. On the other hand, external validity refers to the applicability of the research findings beyond the research itself. This can raise concerns when using a case study methodology and its applicability to other situations (Gummeson 1991). Therefore, to address external validity this research gives an extensive description of the studied cases and addresses more than one case study.

Reliability is understood as the consistency degree with which empirical findings and conclusion have been conducted by different or by the same researcher and their ability to be replicated whilst having similar results (Emory & Cooper, 1991; Silverman, 2000). According to Yin (1984) the interview protocol is very important to ensure reliability, as it provides insights on the way the interviews where conducted and the themes/questions that were addresses, giving thus guidelines to other researchers on how to reach the same results. Therefore, this thesis provides insight into the interview protocol used in this research, see Appendix B-1.

Generalisability is often a major concern in qualitative researches (Yin, 1984). This thesis proposes a model that is built upon existing theory and emerging information gathered by the studied cases for the phenomenon under investigation i.e. circular supply chain facilitate by a control centre. This model is not attempting to suggest a widely accepted new theory to circular supply chain, but rather provide an overview on what the process of a circular supply chain entails based on existing and emerging theory. The generalisability of this research is enhanced by tying the emergent theory from the empirical analysis to existing theory from the literature review (Amaratunga & Baldry 2001).

PART I

THEORETICAL BASIS

Chapter 3

Theoretical Background

This chapter sets out to describe some fundamental concepts on which the analytical framework builds on. First, some background information about the building industry (Section 3-1) within which the context of supply chains (Section 3-1-1) will be elaborated on to identify their current characteristics and peculiarities. Furthermore, to design a circular supply chain, it is first needed to research how circular economy and the concept of circular supply chains is understood by researchers (Section 3-2).

3-1 The building industry context

The building industry can be understood as a project-based industry influenced by specific geographic circumstances, and the involvement of multiple stakeholders (Vrijhoef, 2011). The dynamic relationship between the different characteristics of the industry, has made the built environment production relatively complex compared to other production industries. This has raised interest among researchers to identify the inefficiencies of the industry. According to the research done by Vrijhoef & Koskela (2005) inefficiencies of the building industry emerge within three levels: (i) product, (ii) production and (iii) industry level, see Figure 3-1.

It is noticed that both the product and the industry level are interconnected with the production process of construction (Vrijhoef & Koskela, 2005). Within the production level three main peculiar features are identified: temporary nature, one-of-a-kind production and site production. Janne (2018) argues that the building industry is built on temporary relationships within the organisations present in a project. In the initiation phase of every new building project different actors are tendered and procured, meaning that no project team is the same for more than once (Janné, 2018). According to Winch (2010), this temporary nature results in difficulties to achieve any type of long-term relationship between these organisations, which contribute to minimal knowledge transferring and systematic approaches undertaken where production could be optimised (Vrijhoef & Koskela, 2005). In addition, it is identified that activities performed by the stakeholders within the network structure of the construction industry are highly dependent on each

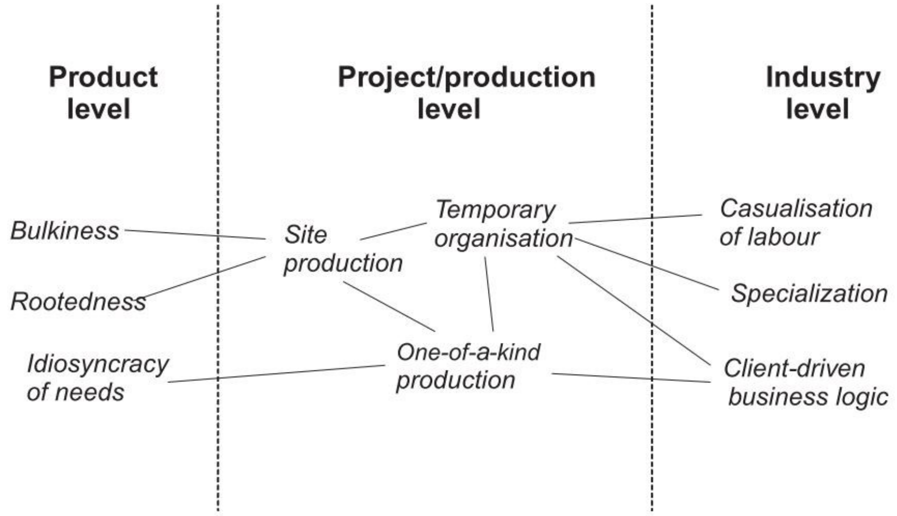

Figure 3-1: Peculiarities of construction on product, project/production and industry level (retrieved from Vrijhoef & Koskela, 2005, p.20)

other (Janné, 2018). According to Winch (2010), the involved stakeholders are aware of the temporary nature, which leads to organisations becoming fragmented. Lundesjö (2015) adds to this that fragmentation is further enhanced due to various specialisations that a project team contains and the temporary nature of building projects precludes long-term knowledge exchange from one project to another (Janné, 2018).

The second peculiarity of site production has a tight relationship to physical aspects of the project location, such as weather and soil conditions (Vrijhoef & Koskela, 2005). These aspects among others create a characteristic production process where repetitiveness becomes difficult to achieve. The production process and the supply chains of a project are both later aimed to converge for delivering to one specific site. Consequently, unique products are being provided which makes up the third peculiarity of the production level: one-of-a-kind production. Projects are impacted by the unique economic, legal, environmental and cultural requirements of the project (Vrijhoef & Koskela, 2005). Due to the one-of-a-kind production and temporary nature, new logistical structures are required to be setup per project (Balm, Berden, Morel, & Ploos van Amstel, 2018).

Furthermore, it is noticed that stakeholders are mainly focused on achieving profits for their own companies thus creating adversarial relationships instead of a collaborative environment (Dubois & Gadde, 2002; Fernie & Thorpe, 2007; Fernie & Tennant, 2013). All of these tendencies seem to add more to the complexity of the project (Tesselaar, 2020). Although some researches argue that fragmentation could affect projects in a positive way as more flexibility is achieved during problem solving moments, there is still a high need for the building industry to enhance the collaboration within their different stakeholders, especially due to the emergence of the sustainable and circular notions (Dubois & Gadde, 2002; Janné, 2018). According to Mentzer et al. (2001) this type of collaboration is only possible to be achieved in an environment where stakeholders obtain and strive for the same supply chain goals.

3-1-1 The building supply chain context

Oliver & Webber (1982) describe supply chains as a systematic collaboration between actors, processes and information flows between similar companies. This collaboration is aimed at developing an end-product or service to be delivered to respective clients (Oliver & Webber, 1982). The Council of Supply Chain Management Professionals (2013) state that supply chains concern activities, such as harvesting, refining and transformation of raw resources to end-products used in construction sites. These processes and activities are executed by a specific organisational network, wherein different stakeholders operate through both upstream and downstream linkages (Christopher, 2011). According to Dulaimi et al. (2007), upstream refers to activities related to the initiation phase of the production on site, whilst downstream controls the delivery-activities of the end-products on the construction site.

Given all the different definitions this paper understands a supply chain as *"a network of interdependent organisations involved in up- and downstream linkages, working together to provide optimal material and information flows to the final delivered product to the client"*. Based on Vrijhoef & Koskela (2000) this definition of the supply chain is visualised in Figure 3-2.

There are several aspects that characterise the structure and function of supply chains. Firstly, it has a converging nature, which means that materials are transported towards the construction site with the purpose of assembling the final product (Vrijhoef & Koskela, 2005). This convergence usually revolves around a single product tailored for a customer, instead of multiple standard products which could be distributed to multiple customers (Vrijhoef & Koskela, 2000). In other words, the lack of standardisation is another characterising element of supply chain, which is as a result of construction projects being led by client demand for the delivery of a 'one-of-a-kind' type of project (Vrijhoef & Koskela, 2000; Lundesjö, 2015). Although the focus is towards one product the current status of supply chains seems to still generate a significant quantity of waste, which seem to be produced in several stages of the process (Vrijhoef, Koskela, & Howell, 2001). This is argued to be due to supply chain stages being independently controlled and monitored (Vrijhoef et al., 2001). Furthermore, the supply chain has a temporary nature due to one-of-a-kind typology of building projects. This results in fragmentation and a distinctive separation between the design and construction phases of the project, where communication between different actors increasingly lacks as the project progresses (Vrijhoef & Koskela, 2000; Vrijhoef et al., 2001). The characteristics of supply chain align and contribute to the peculiarities that were discussed in Section 3-1.

Moreover, supply chains acquire their financial benefits through the income streams that are generated by being part of projects and through knowledge benefits by solving project problems (Winch, 2010). However, benefits are also acquired due to reputation of the companies involved (Winch, 2010). Therefore, the competitive nature of businesses has also translated into competitive supply chains and when addressing collaboration between partners of various supply chains, this involves processing information from multiple companies which as a result creates a highly competitive environment (de Kok, van Dalen, & van Hillegersberg, 2015). This competitive environment and the lack of communication lead to insufficient collaboration, integration and coordination in supply chains. According to Vrijhoef et al. (2001), these issues mainly emerge from late confirmations, failures of informing on time about changes or lack of feedback loops. Thus, there is a need for a

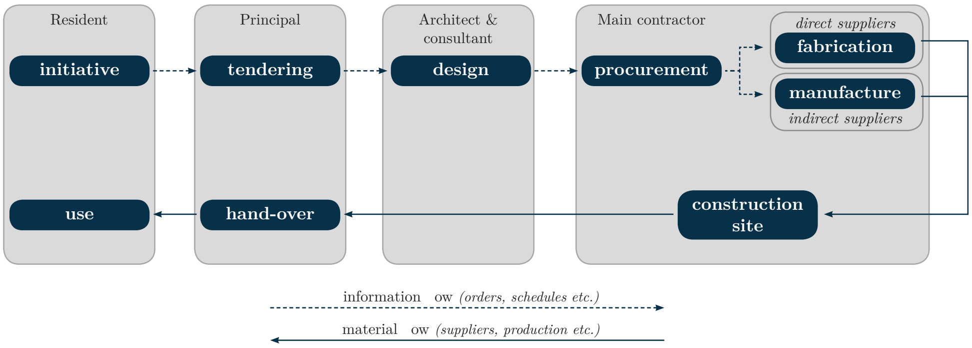

Figure 3-2: A typical configuration of a supply chain (adapted from Vrijhoef & Koskela, 2000, p.173)

control environment that will enhance the communication and collaboration between stakeholders in different project phases.

3-1-2 Decision-Making in supply chain management

Supply Chain Management (SCM) is a concept that originated due to the need of management between all the activities and the different supply chain phases and stakeholders. It *"encompasses the planning, organising and controlling of activities involved in sourcing and procurement, conversion, and all logistics activities"* (Trzuskawska-Grzesińska, 2017, p. 3). Furthermore, SCM aims to achieve trust among supply chain stakeholders collaborations, whilst enabling a transparent environment and defying the aforementioned peculiarities (Vrijhoef & Koskela, 2000; Vrijhoef, 2011). Overall supply chain management has been an important field of research as it is seen to have potential in improving the building industry performance (Vrijhoef, 2011).

Ivanov et al. (2017) refines the definition of SCM, by stating that *"it regards the integration and coordination of material, information, and financial flows to transform and use the SC resources in the most rational way along the entire value chain, from raw material suppliers to customers"*. Within SCM, decision-making is considered as the main management task in supply chains, which is focuses on balancing demand and supply by efficiently optimising the supply chain processes (Ivanov et al., 2017). However, the decisions to be taken in supply chains can be categorised based on different responsibilities related to sourcing, production, and distribution, see Figure 3-3. According to De Kok (2015) these decision-making activities encompass three levels which relate to the deliveries into final products:

- Strategic – concern the location and the number of transformation processes together with the responsible executive legal entities.
- Operational – concern the day to day activities that act as a preparation for the execution of these transformation processes.
- Tactical – concern the allocation of these transformation processes to each legal entity.

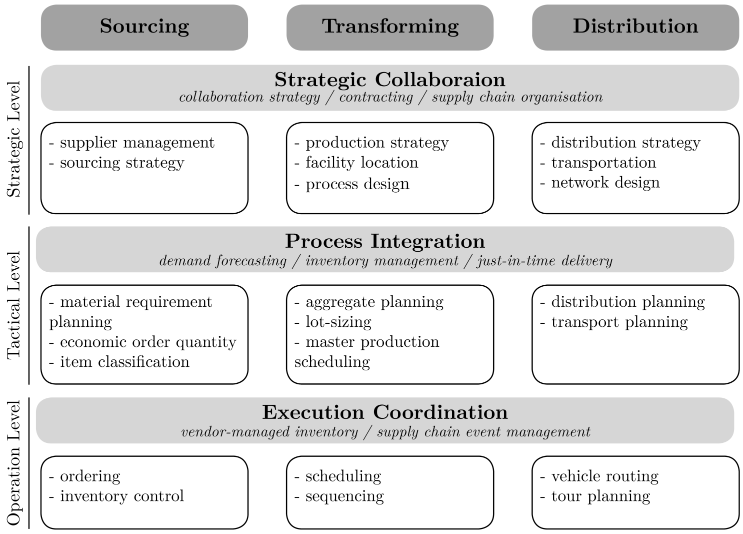

Figure 3-3: Decision matrix in supply chain management (adapted from Ivanov, Tsipulanidis & Schonberger, 2019)

According to de Kok (2015) these decision-making activities aim to satisfy market needs, whilst contributing to temporary and long-term collaboration among supply chain stakeholders. The application of these decision-making activities is significantly complex due to a lack of central control of the supply chain implications (Vrijhoef, 2011).

However, an efficient supply chain management is expected to optimise time management of projects and reduce costs by improving logistics. In Appendix A-1 elaborate information is provided over the logistical discipline within SCM. Furthermore, supply chain management through its decision-making activities acts as a means to make the production and supply of materials in a more efficient manner (Vrijhoef, 2011).

3-2 Circular Economy in Construction Industry

The current built environment is confronted with several transitional challenges like circularity and digital transformation, which require behavioural and process changes to accelerate these transitions. Circular Economy (CE) has been introduced as a new economic model to challenge the current linear processes by retaining the value of the used resources, materials and products that flow, which currently is destroyed by linear processes (Geldermans, 2020). The current economic and business models are still to this day characterised by the linear ideologies that could be summarised in three fields of action "take, make, waste" (Storm, 2011). Geissdoerfer et al. (2017), argue that linear ideologies can be broken by taking into consideration the closure of the resource loops as this would preserve their value. Bocken et al. (2016) strengthen this by adding the component of slowing down or preserving the resource loops before closing and narrowing them. The "slowing" components relates to the life-span extension of resources, while the closing indicates the re-purposing of such resources at the end of their life-span to another function (Lüdeke-Freund, Gold, & Bocken, 2019).

Although, there is a wide consensus on the importance in shifting linear processes towards more circular ones, the subject of a shared understanding of CE is still under discussion, see Appendix A-2. For instance, Ellen MacArthur (2013, p. 7) argues that: *"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"*. It is noticeable in this definition that a focus is given to the need of resource re-usability in order to eliminate any excessive waste. On the other hand, The Ministry of Infrastructure and the Environment (2014, p. 1) argues that CE is *"an economic system that takes the re-usability 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"*. These understandings of CE revolve around the relationship between natural resources and the economic system. According to Schouten (2016), the aspect of re-usability of material resources and economic benefits should neither be free-standing nor exclude each other, but rather be integrated. Ness & Xing (2017) enforce this by stating that by making such decoupling it will result in economic growth and at the same time also responsible resource consumption.

Each of the given definitions provided in this section add something new to the notion of circular economy. Therefore, it could be concluded that there is more than one side to this notion and several resources, such as energy, emissions, health, materials, need to be considered when trying to implement circular economy. Therefore, in this thesis a CE can be understood as *"an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes"* (Prieto-Sandoval, Jaca, & Ormazabal, 2018, p. 610).

3-2-1 The life cycle of the building layers

The main concept within the different definitions of CE in the previous section, revolve around the idea of decoupling resource depletion, by extending the life cycle of these resources and allowing economic growth without putting pressure on the environment (Pomponi & Moncaster, 2017). However, there is a need to first understand that the life cycle of a building depends on the layer in which the components lay in. Thus, the extension will also vary per layer. According to Brand (1994), a building consists of to six layers (site, structure, skin, services, space-plan, stuff), see Figure 3-4.

The materials present in each of these layers have a distinctive life cycle. A research conducted by Crowther (2001), investigated the different life expectations that each of the layer, based on the estimation of eleven different researchers. Different researchers assigned different times, as these were assigned based on a specific criteria of the researcher, see Appendix **??** for more information. However, it is noticed that by different researchers it is accepted that each layer and the materials within them, have a different life expectancy. Table 3-1 provides an analysis of the average life cycle duration for the different layers.

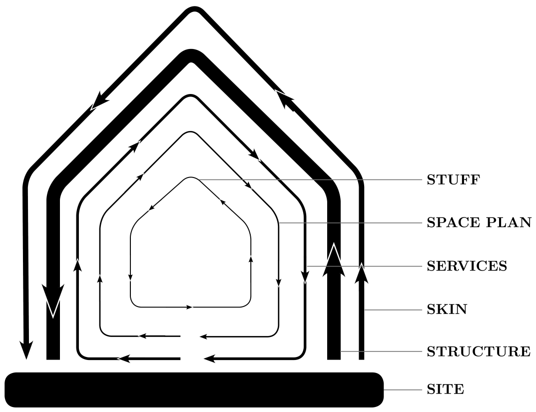

Figure 3-4: Building layers (retrieved from Brand, 1994)

Table 3-1: Life cycle expectancy based per building layer

Building layer	Life cycle expectancy bandwidths
Site	eternal
Structure	20-60 years
Skin	25-50 years
Services	15-30 years
Space-plan	5-15 years
Stuff	1-5 years

The discussion on resource life cycles creates the need to also distinguish between the different life cycles phases of a building project. Each phase requires different application activities. According to Adams et al. (2017) these application aspects are often applied in specific project/sector phase and little attention is being put into the application of these aspects as a whole process. Currently, the most attention and application examples are seen to be done in the design phase and on the material choices of the transformation phase (Adams et al., 2017). This comes due to the short-term thinking and lack of business models that create responsibility for the products and materials that reach their end of service-life (Adams et al., 2017). Although design strategies, such as designing for disassembly, could initiate the creation of more circular environment, by slowing down resource loops and maintaining the value of these resources longer (Ness & Xing, 2017); it does not guarantee that the outcomes will be reached if the supply chain collaboration is not well-established. This will be further elaborated on in Chapter 7.

3-3 Framing circular supply chains

Circular Economy within the building industry aims to optimise resource utilisation by reducing raw material consumption across the sector. According to Muñoz-Torres (2018), supply chains are a crucial element for the implementation of circular economy. Extensive research is being done both in research and practice to implement CE in the building industry. However, the implementation is hindered by obstacles linked to the aforementioned peculiarities of the industry. González-Sánchez et al. (2020) argues that this implementation revolves around two main aspects: extending durability of products and materials and extending the life-span these products and materials are used (González-Sánchez et al., 2020; De Angelis, Howard, & Miemczyk, 2018). Thus, both pillars aim in its essence to extend the life cycle of products in utilising them in various projects. To achieve these two pillars, there is a necessity to reconsider the production processes, where in best case scenario these processes would obtain a regenerative and restorative perspective (Avdiushchenko, 2018). Furthermore, Guo et al. (2017) argues that another crucial improvement towards creating a circular supply chain is the integration and collaboration between the production and distribution processes. This implies that various actors of the supply chain including manufacturers, suppliers, logistical parties and other distribution operators should establish a collaborative process. Enhancing the collaboration between the different supply chain actors enables for data, material flows and responsibilities to be shared in a transparent manner within this connected actor network (Dong et al., 2019).

Achieving a Circular Supply Chain (CSC) would mean the provision of self-sustaining production systems, where materials are returned to such systems, thus reduction of waste generation (Genovese, Acquaye, Figueroa, & Koh, 2017). When dealing with the return of materials and products back in the system of production the term "Reverse Supply Chain (RSC)" arises. Building on the definition of Guide & Wassenhove, Nasir et al. define RSC as *"a series of activities that are required in order to retrieve a used product from a customer and either dispose of it or reuse it"* (Nasir, Genovese, Acquaye, Koh, & Yamoah, 2017, p. 444). This emerges as an adaptation for circular needs to SCM and as a way to maximise value creation throughout the entire life cycle of products (González-Sánchez et al., 2020). There have been also additional definitions to the concept of circular supply chains, where the terms of open- and closed-loops or reverse supply chains have been mentioned. For a more elaborate overview of these definitions see Appendix A-4. The different terms, collectively proclaim the necessity to rethink the production environment, in such a way that attention is put on nine Rs (refuse, reduce, reuse, repair, refurbish, re-manufacture, re-purpose and recycling). Addressing these Rs could facilitate more efficient production processes and transform the building industry towards a restorative and regenerative perspective (González-Sánchez et al., 2020). However, the implementation of such production processes across multiple organisations have been observed to be more complex than internal application.

3-4 Contributing topics to circular supply chains

Besides the aforementioned conceptualisation of circular supply chains, additional concepts have been been raised in literature that directly or indirectly contribute to the circular supply chains (Table 3-2). These contributing concepts give initial shape to the concept of circular supply chain which is further developed in the course of the research.

Table 3-2: Overview of contributing topics to the concept of circular supply chain

Concept	Contribution to CSC	Sources
Reverse logistics	Reverse logistics allows for building components to be harvested and returned to either the original or third parties, enabling for their value to be recaptured.	Taghikhah et al. & Bektas et al.
Co-makership	Involvement of suppliers and subcontractors in early phases by integrating design and product transformation phases.	Vrijhoef
Modularisation and standardisation	A modular approach to the design, production and construction enables standardisation, which facilitates for these standard products to return in other life cycles.	Vrijhoef & Bask et al.
Offsite (pre-)fabrication	Offsite prefabrication activities can contribute to improved quality and production processes and optimal usage of resources, which goes in line with the CE principles.	Vrijhoef; Koskela

3-4-1 Reverse logistics of building supply chains

Reverse logistics is another crucial element for circular supply chains (González-Sánchez et al., 2020). By establishing reverse loops to harvest building components reverse logistics is generated as distributions are made to the original producers or third parties (Taghikhah, Voinov, & Shukla, 2019). So far, waste management has been a crucial element in supply chains and has attributed to the creation of incineration plants where waste is burned to generate energy. Waste management analyses disposition options, such as recycling to raw material elements, incineration or landfill (Taghikhah et al., 2019). Currently, this activity is supplying approximately 250,000 homes with electricity per year, from the incineration of 300,000 tons of waste (Millicer, 2018). This has become a profitable activity in the Netherlands, as it is generating energy. However, the principle of CE is to first re-utilise instead of immediately incinerating for the obtaining the short-term benefit of generating energy. A CSC does not focus only on waste management possibilities, but it expands to activities that minimise the waste and enable product and material extraction that can be returned into other life cycles,in order to recapture their value (Taghikhah et al., 2019).

Currently, logistic distributions cover around 30% of the total Dutch CO_2 emissions and if reverse loops are established, extra logistical routes are generated. Therefore, in order to provide a circular environment and less environmental impact, new transportation modes need to be researched (Quak et al., 2011). Bektac et al. (2016) state that a possible way to reduce such impacts would be by establishing "vehicle routing", which translates to the optimisation of routes vehicles take. Optimising route selection could potentially reduce not only emissions but also costs, energy and fuel consumption, travel time and the number of vehicles used per project (Bektaş et al., 2016; Lin, Choy, Ho, Chung, & Lam, 2014).

3-4-2 Co-makership in supply chains

Co-makership can be understood as the project process becoming more integrated, where suppliers are involved in earlier process phases. This concept has been adapted in the building industry in the shape of on-site assembly of integrated parts to an end-product (Vrijhoef, 2011). This concept aligns with the implementation of a circular supply chain, with regard to the early involvement of suppliers and integration of the design phase with the product transformation phase, as it would make integration of CE concept more efficient.

3-4-3 Modularisation and standardisation

The concept of modularisation has been a popular concept within the building industry for decades, as it provides flexibility in the production environment. Besides improved flexibility, common advantages of modularisation include the simplification of complex processes to standard ones while still providing product variety (Bask, Lipponen, Rajahonka, & Tinnilä, 2010). Within the building industry modularity can be expressed through the production perspective, where products are composed of standardised and independent modules that can be added or removed from the unit without the need of destruction. The modules enable for creating various configurations of end-products (Vrijhoef, 2011). However, modularity can also be observed in the processes of the supply chain, which allows for the process to be broken into standard sub-processes. This allows for quick responsiveness to be achieved due to change of requirements (Bask et al., 2010). Modularisation in the building industry enables the standardisation of processes, which can contribute to scheduling optimisation and overall building time and cost. A modular approach to the design, production and construction enables standardisation, which facilitates for these standard products to return in other life cycles. However, as building processes consists of collaboration of independent companies, standardising the processes between them may require additional coordination mechanisms and platforms as compared with products. Examples can include information systems and contracts.

3-4-4 Offsite (pre-)fabrication

Pre-fabrication has been created as a result of the aforementioned concepts, which require the transferring of activities offsite. There are several implication to transferring activities offsite, such as potential extension of assembly time, high spatial and dimension accuracy is needed which could contribute to the error and correction to take longer (Vrijhoef, 2011). Overall the entire process becomes more complex and vulnerable to errors and correction activities, compared to the onsite activities (Koskela, 2000). However, benefits can also be present to offsite production, such as improved quality and production processes and optimal usage of resources, which goes in line with the CE principles.

3-5 Reflection on key aspects of this chapter

This chapter has presented the background information on the current building industry context and its peculiarities within them, and the circular economy within the. These two concepts helped frame the concept of circular supply chains, which will be further elaborated on in the course of the research. Each concept discussed provided indications on the contributions and limitations with regards to circular supply chains.

Chapter 4

Analytical Framework

In the previous chapter the concept of circular supply chain was framed based on the theories found in building literature. This chapter will take a step further by presenting a theoretical framework on multiple perspectives based on general theory. This analytical framework aims to explain how the organisational structure and operation of circular supply chains from four theoretical perspective environments: production, organisation, control environment and social environment. Each of these environments will be elaborated on, within which several detailed variables of analysis will be identified. At the end of the chapter the information derived will be operationalised into an analytical model, which will be used for the empirical analysis.

4-1 Explaining the multi-theoretical framework view on circular supply chains

In order to understand the dynamic interaction between organisation and human perspectives within the circular supply chain, a multiple analysis environment is required. Since the thesis focuses on the circular implementation within building supply chains, corresponding topics of SCs and CE apply. To this end, some main theoretical perspectives in strategic management literature are taken into account.

First, the building supply chain is composed of different companies that collectively deliver outputs via internal business activities. Therefore, the resource-based perspective within the strategic management is considered as a means to have a better understanding on the internal alignment of companies and the way they adapt their resources and operations to market changes (González-Sánchez et al., 2020). According to Mousavi et al. (2018), the circularity concept requires companies to coordinate their dynamic operations and processes in such a way that are aligned to circular principles. Therefore, *"the resource-based perspective is considered an adequate topic to understand whether the applied resources by companies are relevant for closing production loops without affecting the level of competitiveness"* (Portillo-Tarragona, Scarpellini, Moneva, Valero-Gil, & Aranda-Usón, 2018, p. 3). For the purpose of this thesis the perspective is broadened to the *organisational environment* of circular supply chains.

The industrial ecology is another perspective within strategic management literature, that enables the understanding of how the industry functions, examines the flows of materials and energy and how they can be efficiently closed (Sumter, Bakker, & Balkenende, 2018). According to Gonzáles-Sánches (2020), a circular supply chain may incorporate aspects of the industrial ecology, which take into consideration the service-life duration of products within the value chain and their recovery at the end or their useful life (Sumter et al., 2018). This implies that the focus shifts from product quantity production systems to the producing effective life-cycle products (González-Sánchez et al., 2020). Industrial ecology is understood in this thesis as the *production environment* of circular supply chains. It should be noted that this environment is significantly influenced and interconnected to the organisational one. The chains can clarify the complexities lying between the interconnections between the production phases and respective stakeholders

Furthermore, the implementation of circular economy in supply chains raises the need for the building industry to be monitored and adaptive to production and organisation management changes (González-Sánchez et al., 2020). Therefore, a technological environment, within which smart tools enable this monitoring and efficiently adapt to circular supply chain demands are a necessary perspective to be considered. This makes the third theoretical framework environment: *control environment.*

Lastly, the traditional supply chain environment identified the importance of governance mechanisms, such as trust, optimal transactions, improved coordination and reduced information asymmetry. Although these aspects align also with the circular supply chain configuration, they reach a higher dimension, which requires organisations to shift their cultural mindset to a more collaborative environment. In addition, to the cultural mindset, other *social environment* aspects also need to be examined as CE requires new regulations, rules, financial and social models (González-Sánchez et al., 2020).

From the perspectives discussed this thesis identifies four main environments of research: (i) production environment, (ii) organisational environment, (iii) control environment and (iv) social environment. In the following sections each will be further elaborated on and their variables will be identified.

4-2 Production environment | Opertionalisation of circular supply chains

The production environment of building supply chains revolved the management of transformation activities and flows of materials and information running through processes, with the aim to fulfil customer needs (Koskela et al., 2000). Within the production environment there are three management areas that focus in bringing forward the goals of production: project management, process management and value management. According to Bertelsen & Koskela (2002), project management ensures the delivery of the project conforms to the contractual agreements, whilst maintaining the value defined through the design & construction specifications and operations. On the other hand, process management focuses on the production flows and the processes that lie within it. In the end, the outcome of these processes provide the value to the client, which is managed by value management (Bertelsen & Koskela, 2002). According to Vrjhoef (2011), value can be seen from the product perspective, which is safeguarded through processes and operations and from the process value, which is generated through monitoring the operations, quality, time and costs associated to them. When introducing circularity the production symbiosis is noticed to change from the traditional one. To this end, linking value to the processes would require new process structures that favour transformation activities and overall coordinated adaptations of control (González-Sánchez et al., 2020).

4-2-1 Analysis variables of the production environment

The implementation of circularity in supply chains implies that changes are required specifically in the production environment. For this purpose, fundamental related concepts will be further elaborated on, making up the analysis variables for this environment.

Operation and process coordination

A circular supply chain requires for the involved stakeholders to coordinate their activities by providing overall effectiveness and efficiency of the production flow. The production flow can be understood as the flows of materials and operations, within which coordination of the supply chain is intensified (Vrijhoef, 2011). By implementing circular needs, the production flows are particularly focused in the reduction of waste and increased resource efficiency. However, in order to achieve these changes, decision-making moments will need to consider whether use of raw of materials is refused or reduced and secondary materials are used (Kraaijenhagen, Van Oppen, & Bocken, 2018). However, the ability to apply certain production decisions are depended on the type of project and the organisation structure of it (Melles & Wamelink 1993).

Analysis variable 1 *| Organisations in the supply chain have coordinated their processes and operations to achieve flow, and increase the effectiveness and efficiency of a circular delivery process.*

Circular reverse supply chains

A reverse supply chain could be either open or closed loops and it is important to understand the difference between them. Open-loop supply chains suggests that products and materials are recovered by third parties that were not the original producers, but still capable of reusing them (González-Sánchez et al., 2020). Whilst closed-loop chains are return such products and materials to the original manufacturers with the intention to reuse them partly or fully (French & LaForge, 2006). In addition, Hussain & Malik (2020) expand these closed loops to reverse logistics which include 4 R's: repair, reuse, re-manufacture and recycle.

Currently, the recovery is mainly done at the end-of-life of these products. Although, in principle recovering such products at the end of their life seems a step towards a circular environment, this recovery is done already at the end of the product's life when the only solution is to down-cycle, which does not satisfy the circular principles. In addition, this recovery process also makes use of additional energy and polluting emissions due to extra logistical matters of transporting and subsequent treatment of the recovered products (Taghikhah et al., 2019). Therefore, these logistical issues and the information flow need to be properly addressed to create an optimal circular environment.

Analysis variable 2 | *The functioning of circular supply chains requires new processes that enable the recovery and returning of products and materials, through open or closed loops, into new life-cycles.*

Strategy integration

Although there has been an increased interest in developing a circular economic system, there is still a fragmentation in the field of building supply chains research and further research is needed on how the circular principles can be implemented in SCs. The classical linear process connects the economic growth directly to the use of resources and energy, while CE understands the industry from a restorative and regenerative perspective, thus creating a disassociation between the two (González-Sánchez et al., 2020; Genovese et al., 2017). Consequently, circular economy challenges the notion of "take, make, waste", by returning possible products/ materials in other project life-cycles (Avdiushchenko, 2018). Consequently, transforming the 'waste' component to three action fields: 'distribute', 'use' and 'recover', see Table 4-1 for the main features of the action fields from different literature sources.

Table 4-1: The action fields of providing a circular economy

Categorisation	Action field	CE strategies	Source
To narrow	Take	Selection of materials and resources based on their potential for recycling, reuse or re-manufacturing.	(McDonough & Braungart, 2002; Stahel, 2016)
		Attention to the resource productivity and process efficiency to reduce emissions	(Lieder & Rashid, 2016; European Commission, 2015)
		Consideration for sustainable energy consumption.	(Cayzer et al. 2016; Park et al., 2010)
	Make	Attention to innovative product design for the purpose of extending their service-life.	(McDonough & Braungart, 2002; Del Rio et al. 2016; Tonelli & Cristoni, 2018)
		The recovery of primary and secondary materials and additional inputs in internal processes	(Park et al. 2010; Li et al. 2013)
	Distribute	The development of a sustainable and efficient logistical distribution to reduce CO2 emissions.	(Lieder & Rashid, 2016; van der Wiel et al. 2012)
		Efficient estimation of flow destinations	(Haupt et al. 2016)
To slow-down	Use	Provision of services, such as maintenance that slows down resource loops by extending the life-cycle of resources.	(Bocken et al. 2016)
		Creating new business models where the final consumer of the building renounce ownership of goods. Thus, product/material retention in the process	(Antikainen & Valkokari, 2016; Stahel, 1998; Tukker, 2015)
To close	Recover	Recovery and return of the products based on their ability to be reused/refurbished, re-manufactured or recycled	(Park et al. 2010; Parchomenko et al. 2018)
		Creating responsibility routes with customers and other actors for the recovery of the products and materials to happen.	Lieder & Rashid, 2016; Tonelli & Cristoni, 2018)

The circular strategies have been categorised into three main groups: to narrow, to slow-down and to close. 'To narrow' entails the maximisation of resource efficiency and use of fewer raw resources in the transformation process (Kraaijenhagen et al., 2018). This would entail for production processes to adapt to the use and re-purpose of secondary materials or full product units (Lüdeke-Freund et al., 2019). In addition, 'to slow-down' focuses on ensuring the service life of materials and products is extended. According to Kraaijenhagen et al. (2018), the extension of life is done by preventive and reactive maintenance during the use phase of the building, or through redistribution. Lastly, by extending the service life of building components and materials, the 'closing' of resource loops could be achieved by redistributing them to other manufacturing processes (Kraaijenhagen et al., 2018). Thus, the production symbiosis uses the output of a process as input for another process.

Analysis variable 3| *The production processes incorporate circular strategies that contribute to the narrowing, slowing down and closing resource loops running through supply chains.*

4-3 Organisation Environment | Stakeholder Network Analysis of Building Supply Chains

The construction of a building is usually executed by a project team, which constitutes of different stakeholder. These project teams are temporary collaborations between different stakeholders, specifically created for a certain building project. However, the stakeholder functions always constitute to certain roles within these project teams, such as clients or project developer, municipality departments, designer, contractor, sub-contractor, specialist, supplier, logistical provider and demolishing company (De Bes et al., 2018). Typically, these are the traditional stakeholders that collaborate intensively and frequently communicate within a construction project. A distinction is made between public and private stakeholders, as this plays an important role on the alignment of their role, influence and interest within a construction project. Furthermore, Ness & Xing (2017), note that although mentioned in a singular form, there can be over one stakeholder representative per function. Although different stakeholders are involved in various projects they still constitute to similar sets of organisation functions. In addition, each organisation function hold different roles and objectives within the project process, see Table 4-2.

Table 4-2: Traditional construction project stakeholder functions, roles and their objectives (based on Chinyio & Olomolaiye, 2009, p.78)

Category	Function	Objectives & Roles
Internal Stakeholders	Public client (Municipality)	Ensure the public interest and funds are safeguarded; allocates funds and other contextual guidelines to the project; ensure the project is completed successfully.
	Private Client (Project Developers)	Support the organisation strategy and financial resources by maximising return and minimising risk; purchase the delivered building; ensure the project is completed successfully.
	Designers	Develops design plans of the project that are in line with the requirements of the client.

Table 4-2 continued from previous page

	Quantity Surveyor	Advises client on financial and budget matters; prepares and oversees the tendering process; assesses the submitted tender documents and prepares final accounts.
	Structural Engineer	Develops the structural plans and calculations of the building, while ensuring statutory compliance.
	Building Service Engineer	Develops the plans on the service components of the building, such as plumbing, electrical and mechanical systems.
	Main Contractor	Carries out tasks that translate designs to reality, by taking care of planning time, costs and quality objectives. Manages work on- and off-site of all sub-contractors, suppliers and deliveries.
	Sub-Contractors	Carry out tasks assigned by the main contractor
	Suppliers	Supply materials and products that constitute the finished building.
	Logistic Providers	Arranges transports for construction materials and products between suppliers and construction site.
	Demolishing Company	Provides the collection and processing of 'waste' streams from the construction site.
	Other consultants	Assistance in developing the program of requirements; advise on specific topics and the designs; ensure quality requirements are met.
External Stakeholders	Public External Parties (e.g government authorities)	Ensure the project abides to the building laws and regulations.
	Private External Parties (e.g local residents/businesses)	Ensure that the local businesses and residents are taken into account in the project plans, by creating little hindrance.

Table 4-2 provides the organisational functions that are traditionally involved in a construction project. However, over the past years, the stakeholder network has become more complex as a result of increased demand and need for specialised knowledge for the processes within construction projects (den Heijer & van der Voordt, 2004). The implementation of circular principles within construction is an example of this need on introducing specialised circular advisers and consultants within the project team. When dealing with circular project Adams et al. (2017) identifies the following traditional stakeholders as critical in decision-making moments for circular buildings: designers, contractors, suppliers, demolition companies, municipal representatives, clients. However, additional stakeholders are required to be introduced, such as the aforementioned circular consultants. According to Addis (2006), salvage dealers are another stakeholder that could be added to the circular process of a project. Such dealers, identify and recover building products and materials that can be re-purposed into the cycle, by placing them in an open platform accessible to third party purchases. A reclamation expert is also Gorgolewski (2008) mentions also the importance of involving a dismantling stakeholder, which could provide information on the deconstruction of buildings in parts that can be re-purposed instead of demolished. Currently, traditional companies are expanding towards this new role and attempting to deconstruct building without demolishing them (Kraaijenhagen et al., 2018). An example of this, is the company New Horizon which has changed their business model from a demolishing to a dismantling processes. This is seen as a shift in attitude and behaviour, which is a crucial aspect when implementing circularity (Kraaijenhagen et al., 2018). In addition, a ‘transformation agent’ is another stakeholder, who would take the lead and steer other stakeholders towards circular goals (Kraaijenhagen et al., 2018). Beside the internal shift in attitude and behaviours of all involved stakeholders, the implementation of circularity also requires people that initiate, inspire and accelerate the process. For example, such a ‘transformation agent’ is seen to be adopted by real estate developers Re:Born, who are initiating and becoming front-runners in the .

Circularity brings with its new strategies and change of systems thinking, increased risks (N. Bocken et al., 2013). Therefore, additional facilitating stakeholders have been identified who can assist in creating a circular environment by mitigating these increased risks in terms of legal, financial and logistical requirements. Logistics is seen as an important role as it enables the transportation of harvested products/materials to potential new suppliers or manufacturers that can re-purpose them in new building life-cycles (Lüdeke-Freund et al., 2019; Kraaijenhagen et al., 2018).Table 4-3 provides an overview of all the stakeholders that could assist the implementation of circularity. However, this does not mean that new actors need to be introduced in the process. As seen in the example of Demolishing company A and Developer B the activities of these circular stakeholders can be adopted by traditional actors.

Table 4-3: Circular-related stakeholders

Category	Function	Role
Leading actor	Transformation agent	Ensure that existing buildings are taken into account and their service
Circularity Experts	Circularity expert consultant	Have specific knowledge in implementation of circularity; advise on actions to be taken for the implementation of circular strategies
	Salvage dealer	Identifies building component and materials that can be re-purposed in other construction projects.
	Performance certifier	Able to evaluate and guarantee the performance of the salvaged products and materials.
	Reclamation expert	Has knowledge on the salvaged goods and their allocation, so that they can be bought or reclaimed.
	Dismantling expert	Has specific knowledge on how to deconstruct a building instead of demolishing, by adding more value to those components and materials.
Facilitators	Reverse logistic service providers	Ensure that the deconstructed and salvages building components and materials are transported to the proper locations, for re-purposing reasons.
	Legal parties	Support the circular process by mitigating risks in regards to legal requirements, in the shape of contracts.
	Financial analyst	Support the circular process by analysing and mitigating any financial risks when dealing with a circular project.

Construction projects include multi-stakeholders from the initiation phase through the construction process to the operation phase. As each stakeholder has different objectives this could result in the rise of conflicts between these objectives. Therefore, it is necessary to identify the level of power and interest of the involved stakeholders in construction projects and the interrelationships between each other specifically for a circular project.

Stakeholder interrelationships within the project phases

The stakeholders in a construction project are closely interrelated with each other, usually by means of contractual or informal agreements. The internal stakeholders are linked via legal contracts or personal interests, while external stakeholders is mainly linked indirectly and informally to the project. Although it should be noted that these external stakeholders may still have some type of influence into the project. The relationships of project stakeholders are depicted in Figure 4-1 and the information of these interrelationships in the different project phases are based on Chinyio & Olomolaiye (2009), den Heijer & van der Voordt (2004), Kraaijenhagen (2018) and Addis (2006).

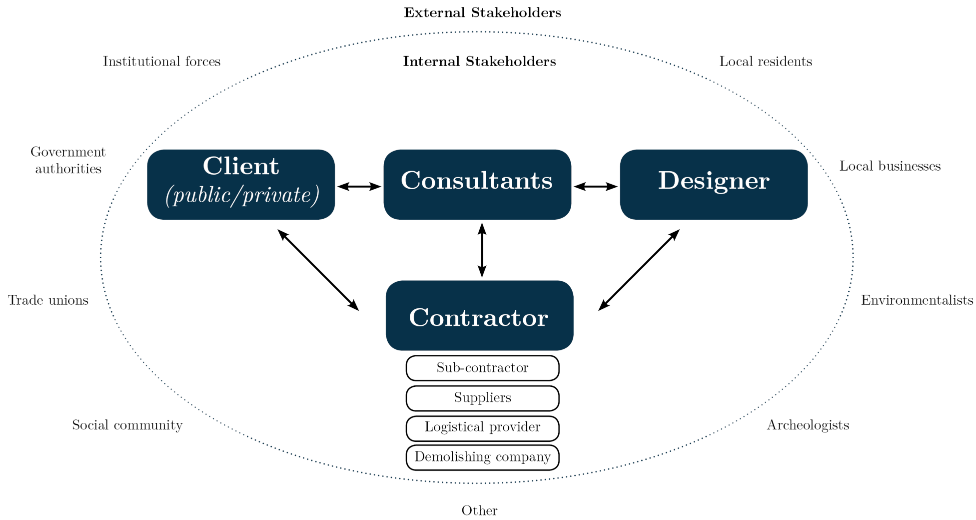

Figure 4-1: Interrelationships between the different stakeholder (adapted from Chinyio & Olomolaiye, 2009)

In a linear process starting with the **initiation phase** the main contact moments happen between the client and consultants, who make a market analysis in order to understand the possibilities of the site. Depending whether the client is a public or private organisation there will be also financial estimations or observations on community and local residents' compliance to the ideas. During this phase a program of requirements is drawn up, however often these are not definite and may change throughout the project process.

The **design phase** the project managers, designers, engineers and quantity surveyors are employed to the project. During this stage there are tight interrelationships between the aforementioned stakeholder and the client to ensure the project scope is defined and the design is finalised, whilst ensuring its feasibility. Here the designs are also tested against the regulatory requirements compliance.

The **construction phase** starts once the tendering process has been finalised and has assigned a main contractor to the project. A contractor forms a construction team, within which suppliers, sub-contractors and logistical service providers are present. From the commercial point of view, a contractor has to minimise expenditure and maximise income. During this period it is important for project managers to also be involved and collaborate with the contractors to ensure the project is following its planning without any issues. In addition, they intensively collaborate with suppliers and their sub-contractors, to ensure that the work is carried out and the materials and equipment are supplied as specified according to the designs.

In the **first cycle delivery phase**, the main activity is handing over the completed building to the client. The biggest interrelationships lie between the clients, contractor and project manager to assess whether all the requirements have been fulfilled and performance is attained. Between the delivery stage of the building and the operation phase, there is a liability period, which if defects occur investigations need to happen to estimate who is responsible (often the main contractor is held liable).

In the **operation phase**, property and facility managers are introduced during the operation phase, in order to monitor and either react or prevent to any maintenance issues for the building. Often in a linear process once the operation phase is done and no renovating or transformation plans have been arranged, the building is considered to have reached its end-of-life. However, to create circular economy **additional cycle delivery phases** need to be established, meaning that through transformation or renovation plans reverse loops are enabled. This will be further discussed in Chapter 7.

The interrelationships between the different stakeholders are rather complex and vary with the nature and scale of construction projects. Project managers are seen as important stakeholders as they have interrelationships with all other stakeholders in order to monitor and ensure a swiftly process. Although the nature of project organisation is temporary, the interrelationships sometimes may be long-term. This happens when stakeholders have collaborated in the past for different construction projects and are aware of their working methods, strengths and weaknesses. According to Kraaijenhagen et al. (2018), past collaborations and long-term interrelationships can enable trust and support a higher collaboration between the stakeholders.

Influence on decision-making

Stakeholders involved in construction projects work towards one main mutual goal: delivering a building to its client (den Heijer & van der Voordt, 2004). This aligns the stakeholders to communicate and coordinate with each other in order to fulfil this objective. However, as it has been mentioned also in the literature framework, that process also has an uncooperative nature to it. This comes due to the personal interest that stakeholder hold (Wamelink, 2010), making thus the building process and the decision-making moments a combination between collaboration and personal interests. In Section **??** and 4-3 the stakeholders of a project team and their interrelationships have been identified. The internal stakeholders of a project have formal influence in decision-making moments. Based on the information provided in these section, a stakeholder environment has been visualised, where a distinction between the stakeholders in direct and indirect environment is made, see Figure 4-2. In addition, a distinction again is made between the reclaimed traditional and circular actors which were identified through literature and documentation. Within the direct environment lie stakeholders that have a direct influence into the project process and in the decision-moments whether they be strategic, tactical or operational. On the other hand, the outer layer of the stakeholder environment consists of actors that may have influence in the project but do not exert any power in decision-making moments.

Furthermore, most of the identified circular specific stakeholder are noticed to still have an indirect influence into the project, compared to the traditional ones, meaning that their decision-making power is limited. However, the implementation of circularity requires a shift in systems thinking and behaviour of the traditional stakeholders, which would mean this stakeholder environment would become more merged. In addition, a stakeholder that seems overlapping in both areas is the logistical provider, both for the linear and circular process these providers are necessary to successfully complete construction activities.

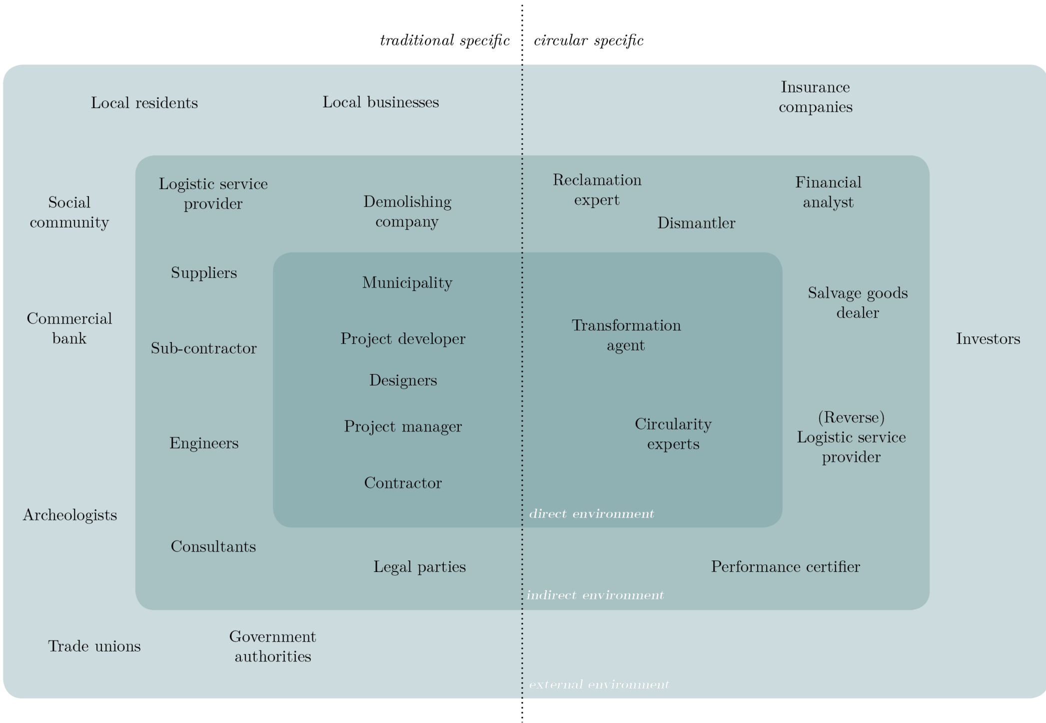

Figure 4-2: Stakeholder Environment

4-3-1 Analysis variables of the organisation environment

The implementation of circularity in supply chains implies that changes are also required in the organisation environment. For this purpose, fundamental related concepts will be further elaborated on, making up the analysis variables for this environment.

Internal alignment

Before the entire circular supply chain processes and organisation interrelationships are achieved, the internal alignment of the involved organisations is necessary. In the case of a CSC the involved organisations should have aligned their internal business activities with circular principles. This may require the development of new business models that include and support internal circular business activities (González-Sánchez et al., 2020). By establishing internal circular business models, circular features in building supply chains are stimulated and enhanced, which can be further complemented by other smart technologies

(Rosa, Sassanelli, & Terzi, 2019; González-Sánchez et al., 2020). Without changing the company's internal alignment, it is hard to align with other companies and achieve a circular supply chain. Circular business models are seen to encourage the transition to circular processes of supply chains (Rosa et al., 2019).

Analysis variable 4| *The focal company is required to internally align their business activities towards circular supporting ones.*

Cross-chain collaboration

As a consequence of the integration of circular principles, supply chain organisations may enter in collaboration with each other in order to achieve the ambitions. There are two collaboration types in supply chains: internal and external, see Figure 4-3. Internal collaboration is mainly done between the different departments of the same organisation (Barratt & Oke, 2007). On the other hand, external collaboration is mainly done on a vertical axis, but it should be acknowledged that there is also a horizontal axis to it.

Vertical collaboration in a supply chain can be understood as the collaboration between project stakeholders, such as clients, contractors, architects, or suppliers (Staring, 2019). While horizontal collaboration occurs mainly between businesses that obtain the same position in the chain, for example, the collaboration between two different logistics service providers or two different suppliers (Staring, 2019). However, this horizontal collaboration is often difficult to achieve due to businesses wanting to maintain the aforementioned competitive environment. According to de Kok et al. (2015), horizontal collaboration must be facilitated by vertical collaboration to be effective.

Analysis variable 5| *Cross-chain collaborations should be established between different organisations within the supply chain through strategic/contractual agreements.*

Information exchange

In order to support circular implementation in the production environment processes, organisations should increase the levels of information sharing internally and beyond company borders, with other supply chain stakeholders. The requirement is that stakeholders are constantly informed on the status of the supply chains that they are involved. However, this relies on the availability and willingness of information sharing, a joined information system or the integration of multiple ICT systems that are used by different stakeholders. Cheng et al. (2010) argue that such system integration will require trust and coordination within the involved stakeholders, leading to the need of governance models to ensure this information exchange.

Analysis variable 6| *Organisations are required to increase their level of information sharing both within and beyond supply chain borders.*

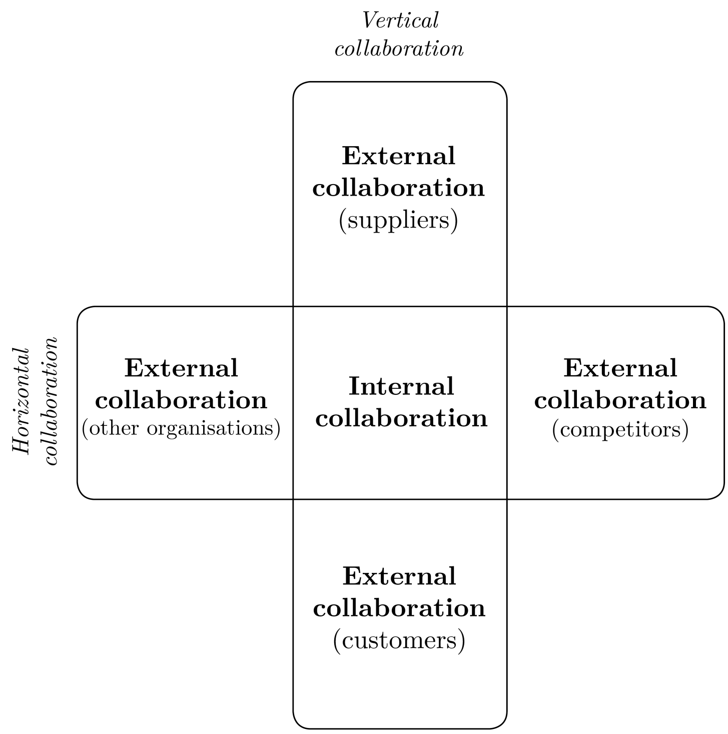

Figure 4-3: The scope of collaboration (adopted by Barrat, 2004, p.32)

4-4 Control Environment | Technological uses in the building industry

Considering the new requirements that circular implementation requires, the building industry, particularly its supply chain, requires a deliberate monitoring environment (González-Sánchez et al., 2020). Over the past few years, the supply chain control environment requires higher visibility particularly in the production processes. Supply chain visibility relates to the ways how organisations capture and handle the gathered information to extract critical activities that need to be executed and eventually share this information to different parties (Bhosle et al., 2011). Providing visibility contributes to the overall efficiency of the supply chain in four critical areas: (i) agility, (ii) resilience, (iii) reliability and (iv) responsiveness, see Figure 4-4.

Heaney (2014) states that supply chain visibility is understood as having awareness and control over the three types of supply chain management activities (strategic, tactical and operational) which are enabled due to the interactivity between people (organisations), systems (technologies) and processes, see Figure 4-5. Barrat & Oke (2007) further argue that supply chain visibility is *"the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations, and which they consider will be of mutual benefit"*.

New smart technologies facilitate circular changes, which are required to the production and organisation environment. For instance, supply chain control centres have emerged as a response to the need for more visibility in the supply chain (Trzuskawska-Grzesińska, 2017).

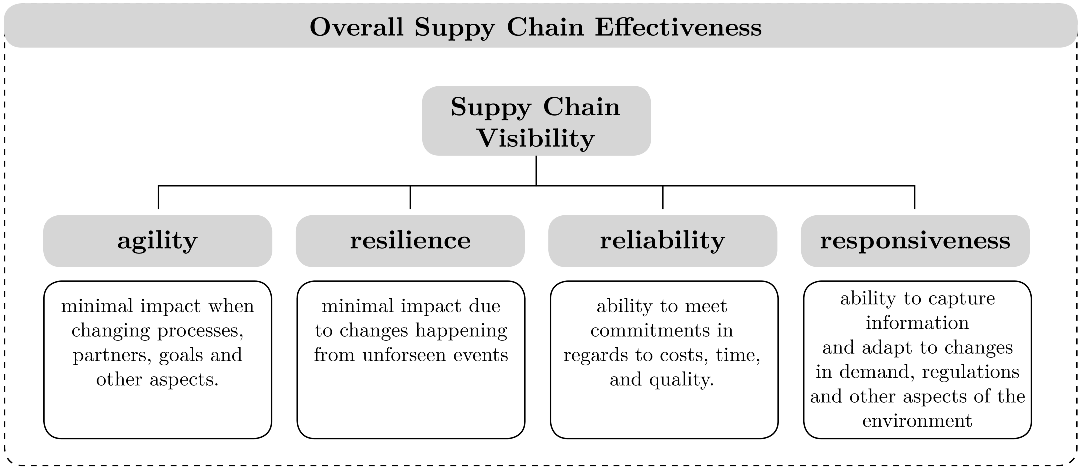

Figure 4-4: Four areas being influence by supply chain visibility

Control centres can be seen as a system that provides supply chains an optimal visibility of the demand and supply side trading network operations (Trzuskawska-Grzesińska, 2017). Christopher (Christopher, 2011) argues that this visibility is captured by such control centres through technology, organisation and processes that provide information on product movements. Therefore, a control centre could be understood as a tool that is able to monitor, measure and report in real-time information to different actors in the supply chain in order to improve efficiency, timing and service, and allow such actors to achieve their strategic objectives (Greene & Caragher, 2015). Mena et al.
(2014) and van Doesburg et al. (2014) add that for the proper functioning of these centres it is necessary to have trustworthy data, well-functioning technology and consistent engagement of the right skilled expertise, design processes and organisation with its interfaces to all partners in supply chain. According to Schauf & Berttram (2018) a control centre helps create a more integral ecosystem. This integral ecosystem differs from a traditional one, as it positions the control centre as a central node for the purpose to reach all stakeholders involved in the process, by sharing information between them. On a conceptual level, the sharing of information is done through the functional components of the control centre, which are interconnected by a data management layer, keeping track of changes (Hofman, 2014; Tesselaar, 2020). In addition, a control centre is expected to make a significant contribution to the achievement of environmental concerns, as by efficiently managing logistics pollution and emissions will be reduced.

4-4-1 Analysis variables of the control environment

The operalisation of control centres could either be physical, fully virtual or a mixture between the two (Dalmolen, Moonen, & van Hillegersberg, 2015). However, whether this be a physical control tower or a virtual control centre with interconnected information systems and tools have specific requirements and functionalities which are identified below.

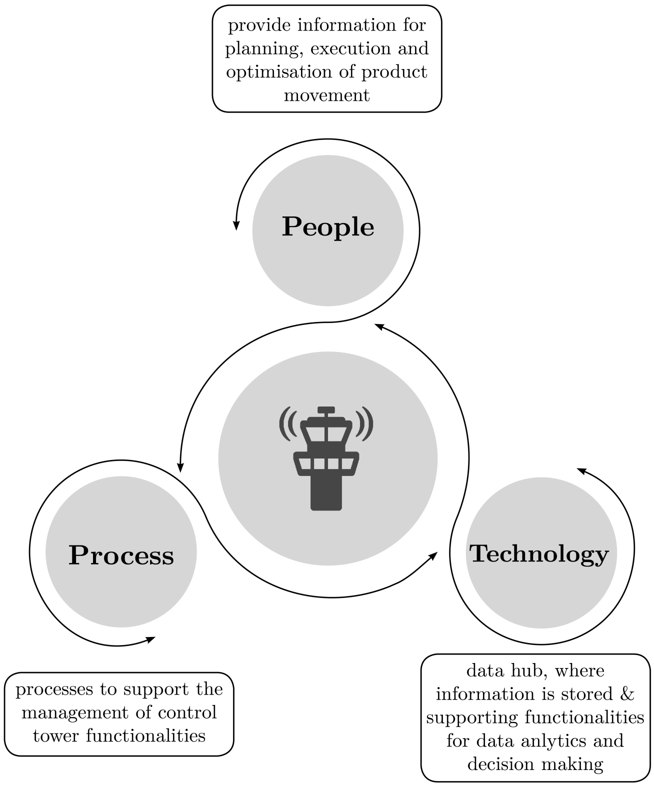

Figure 4-5: The three pillars of a control centres

General requirements of control environment from literature

The implementation of a control environment in a large scale is still hindered by several factors, such as the previously mentioned governance networks, lack of trust and willingness in sharing data (Dalmolen et al., 2015). In addition, when dealing with dynamic business networks that involve actors from different fields proper ICT support is also required (Staring, 2019). However, current ICT support is mainly comprised by technologies for the support of internal processes or static businesses integration, which is not sufficient for the functioning of control centres as it need more advanced IT architectures (Dalmolen et al., 2015). Furthermore, the control centres should facilitate inter-organisational relationships between supply chain actors, which require careful governance. Dalmolen et al. (2015) provides five key requirements for ICT architecture which achieve these inter-organisational relationships: (i) modular structure, (ii) coordination and collaboration, (iii) quick connect capability, (iv) relationship management and (v) risk management.

First, *modular structures* in products and services are thought to simplify the coordination and integration of logistic services (Tanriverdi, Konana, & Ge, 2007). These modular structures are understood as independent modules that can be used and adapted in different situations. Hoogewegen et al. (1999) argue that modularity provides benefits towards assessing quality and for price comparisons. Secondly, *coordination and collaboration* are two crucial components when dealing with a multi-actor network. This requires for protocols, tasks and decision-making techniques that involve accordingly different actors

(Dalmolen et al., 2015). Dekker (2004) states that for an efficient inter-organisational coordination mechanisms that control outcome by goal setting and performance monitoring, behaviour by structural specifics and social characteristics by partner selection and trust building. On the other hand, *quick connect capability* refers to the control centre being a hub for dynamic network integration for multi-actor networks. Both quick connection and disconnection capabilities to external partners are needed for the optimal control environment. *Relational management* is crucial specifically for agile and temporary networks, which are characteristic for construction supply chains. In these supply chains subjective loyalty between network partners is not able to be achieved in a short time. Therefore, Mowshowitz (1997) states that 'objective loyalty based on self-interest' is only possible. In addition, Kumar & Van Hillegersberg (1996) argue that a central actor for supply chain control is not likely to be accepted by other powerful actors in the supply chain. According to Staring (2019), information is more willingly shared if equally shared and joint benefits could be gained. The trust can be potentially built with mechanisms that provide past performances and relationship history. Lastly, as multi-actor relationships are dynamic and temporary they are high risk activities on both technical and organisational level. Thus, high quality semantic standards are required to avoid the risk of misunderstandings (Folmer, Luttighuis, & van Hillegersberg, 2011).

Analysis variable 7/ *A control environment is required to have a modular structure, enable coordination, collaboration and quickly connect to systems, whilst managing the relationships and risks within the supply chain.*

General functionalities of control environment from literature

The five key aforementioned requirements clarified the context within which a control centre environment should operate. Within literature, several functionalities and capabilities are identified for an effective operation. Trzuskawska-Grzesínska (2017) states that there is a number responsibilities for control centres, e.g. the monitoring, measurement and assessment of processes, corrective and preventive actions and communicating/reporting orders and issues to representative stakeholders. In addition, a control centre is expected to supervise the balance between supply and demand, the procurement process and its in- and outbound logistics needs (Trzuskawska-Grzesińska, 2017). According to Merrinboer & Ludema (2016) a crucial functionality of control centres is the ability to gather and analyse information for the purpose of facilitating collaboration within supply chains. The ability to capture relevant information for the project facilitates visibility, which eventually supports decision making moments and event management (Bhosle et al., 2011). In order to create a complete overview, it is important to analyse based on literature the possible functionalities that a control centre can provide, as shown in Table 4-4 (Staring, 2019; Trzuskawska-Grzesińska, 2017; van Merrienboer & Ludema, 2016; Bhosle et al., 2011; Tesselaar, 2020). Three main functionality categories are provided; (i) planning & routing, (ii) forecasting, auditing & reporting and (iii) decision making, which are further described based on the three levels of supply management control: strategic, tactical and operational, introduced in Section 3-1-2.

Table 4-4: General literature functions of control centres per level of control

	Planning & Routing	**Forecast, Auditing & Reporting**	**Decision Making**
Strategic	Planning of construction phases	Collaborative information sharing for all stages in supply chain movement	Procurement processes (organisations, locations, materials)
	Determining consolidation options	Establishing end-to-end visibility	Logistical network design
	Planning of material flows	Forecast supply chain demand and finances	Establish key performance indicators (KPIs)
	Planning of information flows		
Tactical	Providing optimal routing to construction site	Generate breakdown reports of the total costs per product	Event management in case of disruptions
	Horizontal and Vertical transport planning	Discussions with suppliers and in regards to loading quality and types of vehicles	Self-correcting actions
	Deployment of logistics coordinator	Assess scenario planning in regards to traffic flow	Auditing and reporting
	Plan in- and outbound logistics		Warnings in case of disruptions
Operational	Real time monitoring and tracking	ETAs estimations/predictions on a daily basis	Hour overview of (non-) essential activities
	Plan delivery time frames	Reporting of needed hours for preparation	Billing and Invoicing
	Real time update of planning and routing decisions	Insight of material/product inventory	Monitoring performance based on KPIs
	Make prediction about daily estimated time of arrival of products (ETAs)	Process monitoring	

Analysis variable 8| *The control environment should obtain functionalities that achieve the monitoring, measurement & assessment of processes, corrective & preventive actions, and communicating/reporting orders or issues to representative stakeholders.*

Control facilitator across supply chains

Grefen & Dijkman (2013) argue that within single supply chains a hybrid control approach needs to be used where centralised and decentralised control merge together, see Figure 4-6. A centralised control can be understood as the chain having one control system which oversee the whole chain processes, while a decentralised control is based on autonomous links in the chain that collaborate on the basis of link-to-link message passing (Grefen & Dijkman, 2013). Although a centralised control may

In a hybrid system the control is managed through bidirectional integration between the involved actors. The information systems (IS) is built up on the basis of information which is provided by the transformation systems (TS) that these actors execute (Staring, 2019). TS basically records all the events that happened in the analysed context, such as purchase orders. While IS gathers the information which is then used by actors for their own control systems (CS) in order to undertake new transformations which are send to other parties, for instance transporting orders. It is important to note that the central CS (CCS) and the central IS (CIS) ultimately represent a central actor who conducts all the tactical and strategic management activities (Grefen & Dijkman, 2013; Staring, 2019). On this level, chain wide insights can be gained and used to steer the different CS (Staring, 2019).

According to Vrijhoef (2011), the centralised control has the potential to improve the joint performance through knowledge transferring and a systematic feedback provision. However,

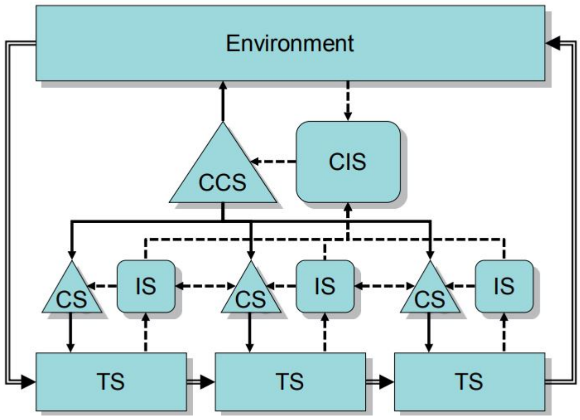

Figure 4-6: Hybrid control model (retrieved from Grefen & Dijkman, 2013, p.48)

a centralised control is accompanied by several consequence, i.e a decrease of autonomy in supply chains, and the emergence of a control facilitator (Ireland, 2004; Vrijhoef, 2011). Depending on which organisation takes the role of the control facilitator, the supply chain could involve other stakeholders through contractual agreements. For example, if the contractors took this role, it could enable the organisation of their sub-contractors and suppliers to produce and deliver integrated products to the market. In addition, several researchers believe that for a centralised or hybrid control environment to work, a neutral third party that is trusted by all parties so that horizontal and vertical collaboration is successful (Staring, 2019).

Analysis variable 9| *A hybrid control approach, facilitated by an independent party is needed, where centralised and decentralised control merge together.*

Circular building tools

Besides the concept of control centres, a wide range of smart tools are being developed with the main aim to evaluate circular implementation in the building industry. For instance, new technologies and tools are being developed claiming to tackle circular strategies that extend the service life of products, or help measure and certify materials being used in supply chains (González-Sánchez et al., 2020). However, it is noticed by researchers that the measurements and certification is currently time-consuming, requires high levels of transparency and should be issued by independent parties (Kibert, 2013). Several advantages are also present, such as higher control over inventory, help in decision making moment during the design and transformation processes, which could lead to 'narrowing' circular strategies.

Analysis variable 10| *The control environment consists of specific circular building tools, which could facilitate the creation of circular supply chains.*

4-5 Social Environment | Analysis on regulatory, financial and cultural factors

The implementation of circular economy in supply chains and its economic viability is highly dependent on governmental support and the legislations and regulations accompanying it (Muñoz-Torres et al., 2018). According to Mangla et al. (2018) an absent regulatory environment is expected to hindrance the circular business activity application within companies. *"Due to the lack of regulatory pressures, organisations tend to continue the status quo of waste management, which is often a neglected part of supply chain operations management"* (Zhang et al., 2019, p. 5). Therefore, the establishment of a legislative system among government, municipalities and industry is necessary to create responsibility on all involved stakeholders and facilitate the linear processes towards circular ones (González-Sánchez et al., 2020).

Among other countries, the Netherlands also aims to shift away from linear and towards circular building methods. This can be seen by the different initiatives and agreements taken between the Dutch government and industry actors, where the construction is one of the crucial sectors. For example, "Transitieagenda Circulair Economie" provides guidelines for the building sector to enhance circular building by 2050 and reduce the use of primary resources with 100%. These guidelines and ambitions of this document are in line with the same ambitions of the Dutch government. However, these still remain mainly in theory instead of being implemented in practice. Currently, more attention is being given to providing an energy-neutral home rather than building in a circular way as a whole process. According to van den Nieuwenhof & Verheij (2018), this is related to financial reasons as high construction prices are justified by the low energy costs, while large-scale circular housing projects do not yield financial benefits on a short term, resulting in many people not seeing the benefit to circular building. According to Mangla et al. (2018), absence of economical benefits in a short term are interpreted by companies as higher costs. This hindrances the initiative of companies to embrace circular applications, which in their core provide financial benefits in the long term. In this line, subsidy possibilities from the government may encourage more initiatives in the market (González-Sánchez et al., 2020).

Furthermore, the circular building projects that are being undertaken are mainly pilot projects initiated by Dutch municipalities, or a number of market parties with ambitions that surpass the national regulatory framework (Geldermans, 2020). Therefore, stricter governmental regulations, which enable responsibility in all supply chain actors are necessary for the implementation of circular supply chains. Besides the regulatory environment, the financial feasibility is another crucial component for obtaining a circular supply chain.

Lastly, the cultural variable that revolves in the application of circular economy principles should be considered. Cultural mindset changes are necessary not only in the society itself but also within businesses too (González-Sánchez et al., 2020). It is necessary to have more organisations sharing the same ambitions and cultural position towards circularity in order to impact the changes needed in the production environment of supply chains.

Analysis variable 11| *The establishment of a regulatory and financial framework, which contributes to the change of the cultural mindset of the society and organisation involved in supply chains.*

4-6 Synthesising the analytical framework

The theoretical background revealed several peculiarities present in the construction supply chain context, where among others the fragmented nature, competitive environment, temporary organisations and one-of-a-kind production make it difficult for an integrated collaboration in the horizontal and vertical axis. As a consequence the management of supply chains is crucial in order to establish a transparent, trusting and collaborative supply chain environment. Besides collaboration, coordination is another important component of SCM, as it mitigates uncertainty by synchronising information and material flows. These activities can be facilitated by IT functionalities i.e., planning and routing of supply chain, monitoring and information sharing. With the help of these IT facilitators, a supply chain environment with information and communication is available is able to enable a timely, correct and full information about the demand and supply along the value-adding chain. Furthermore, coordination is interlinked with integration. SCM enables integration from an organisational perspective (different supply chain stakeholders collaborating together) and from the managerial perspective (strategic, tactical and operational decision-making levels). It should be noted that within each of these SCM components, decision-making is an overarching crucial task that happens through the three levels and addresses sourcing, transforming and distributing responsibilities.

When addressing the concept of circularity in construction supply chains, the aforementioned peculiarities are increased and complexity is enhanced. This is due to researchers and organisations viewing circular economy in different perspectives that address individual aspects, such as energy, emissions, health, natural resources, and economic systems. However, to create a circular environment these aspects need to be jointly taken into consideration. Achieving a circular supply chain would mean the provision of self-sustaining production systems, where materials are returned to such systems, thus reduction of waste generation and enhancement of the building life-cycle. The recovery process is a crucial action field into the establishment of circular supply chains. Currently, this happens at the end-of-life of products/materials, when recycling or down-cycling remains the only solution is to recycle and down-cycle, thus not properly utilising the reverse loops. To prevent this the linear action fields of take, make, distribute and use need to be aligned in such a way that will enable up-cycle recovery loops. However, all these processes and operations are not possible without a functional organisation structure, where the stakeholders collaborate and willingly integrate internally and externally operations that comply with circular requirements. The control environment, also making the third theoretical area of this chapter, recognise that to address the complexity within CSC, the monitoring of this environment is needed. For this purpose, technological advances, such as control centres or other circular building tools are necessary. Lastly, the social environment identified that the regulatory aspect is important to take into account when introduction the concept of circularity. Governmental support, by introducing new policies, plans and legislations, could promote and support the implementation of circular principles into supply chains. In addition, it could also have a positive influence in the cultural and financial factors of CSC.

As a conclusion to the theoretical basis, an analytical model has been drawn, see Figure 4-7. The ideas that have emerged in literature related to circular supply chains and the building control environment, offer direction to the concept to be developed in this thesis. This includes four main theoretical areas as well as their analysis variables, making up the first development of the MCSC environment, which will be further used in the empirical analysis.

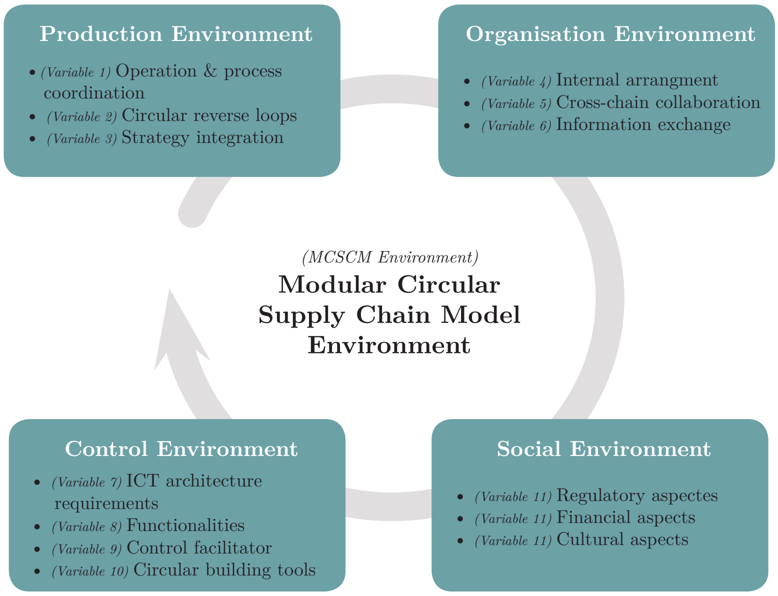

Figure 4-7: Analytical framework of the MCSCM environment

The MCSCM environment is comprised by an integration of the discussed theoretical framework areas. The different blocks of the model are correlated with each other by the propositions enunciated in the theoretical framework and built on the basis of the analysis of the literature. To further clarify what a circular supply chain is, the blocks have been translated to a visualisation of how a circular supply chain looks like based on the theoretical and analytical framework, see Figure 4-8. Figure 3-2, was first used as an under-layer and the model was further built on based on the analytical variables.

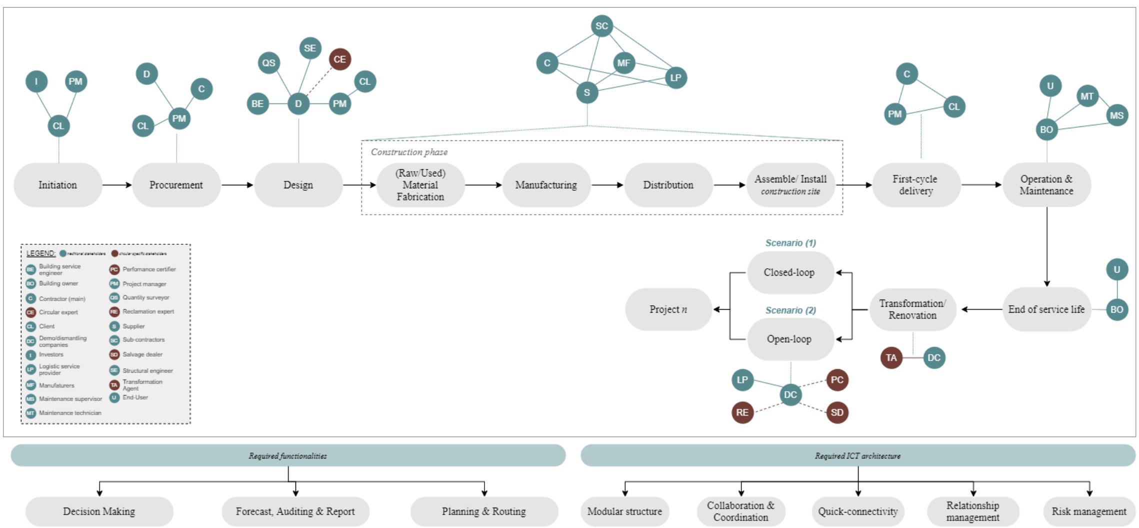

Figure 4-8: The theoretical MCSC Model

PART II

EMPIRICAL ANALYSIS

Chapter 5

Analysing the Control Environment of the Building Industry

This chapter addresses the first part of the empirical analysis: *What tools and information systems are present within the building industry, facilitating a circular control environment?*. First some general coordination and information systems are identified. Next, the circular control environment is analysed by creating a list of existing circular building tools currently present in the building industry. The listed tools will be individually described and then categorised based on their similarities. This list is then tested against the theoretical framework, to understand whether the tools satisfy the corresponding components. Finally, the shortcomings, effectiveness and integration possibilities of the discussed tools are described.

5-1 General coordination & information systems of the building industry

Before analysing the circular specific building tools, it is important to identify some general coordination and information systems in the building industry that facilitate the traditional project processes. The coordination aspect of Supply Chain Management (SCM) can be facilitated by multiple ICT systems. This section focuses on identifying several information systems actively used in the building industry for the purpose of coordinating the different supply chain stakeholders within the building industry. Although, some of the systems may not be specifically designed for the building sector they consist of elements that are applicable to construction supply chains. In addition, it should be noted that these information systems do not claim to facilitate the coordination of circular building projects. However, the identification of information systems used in the supply chain context, will clarify the type of information that a control environment holds. Based on literature and secondary empirical documents *Building Information Modelling (BIM)* is one of the main information systems within the building industry. BIM has been introduced into the market as a software program that collects building project information and facilitates information sharing between different processes of building projects (Papadonikolaki et al., 2015). In recent years, the use of BIM has been embraced by the industry, as it is considered a key component in facilitating coordination and collaboration. This, together with the current advances in ICT, has given rise to software suppliers to develop new software packages that deal with many different types of information within the building industry. These software packages support traditional construction domains, such as architecture, structural engineering, civil engineering, building services, project management, and geographical information systems (GIS) (Abanda, Vidalakis, Oti, & Tah, 2015). BIM software provides 3D models of projects which enable information insights and tools for the design, construction and management (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 2018). In addition, planning and scheduling abilities together with cost related data, which elevate the 3D model to a 5D model are also available (Deng et al., 2019). Although the scheduling of building projects is considered an iterative process, the BIM planning and scheduling abilities seems promising in the facilitation of the process (Tesselaar, 2020; De Bes et al., 2018). Furthermore, the software of BIM allows for quick connectivity to the GIS information system, where information on product inventory and delivery are stored. This could assist the logistical distributions throughout the different stages of the project. However, the abundance of different BIM software packages is creating confusion amongst practitioners about which package to use(Abanda et al., 2015).

Geographical Information Systems (GIS) is another information system, that was developed to manage and analyse spatial data by using functional and physical spatial attributes (Liu et al., 2017). The main difference between GIS and other information systems is the geo-referenced data allocated within it. As a result, location and spatial information together with other attributes related to the project location are crucial components of GIS. Through spatial analyses, GIS enables identifying the implications of the outdoor environment at large spatial scale. However, it lacks a detailed digital repository of building information. Thus, it is desirable to use software packages that bring BIM and GIS perspectives together, as GIS focuses more on real-world modelling, while BIM considers the design process (Liu et al., 2017).

In addition to BIM and GIS, logistic information systems are used in the building industry. However, they lack connectivity abilities to BIM or GIS. These information systems support logistical tasks, i.e. the organisation, control and optimisation of products/materials or other flows of goods and information (Nettsträter, Geißen, Witthaut, Ebel, & Schoneboom, 2015). These tasks are facilitated by planning and forecasting tools that oversee the entire supply chain. General logistic software systems are *Enterprise Resource Planning (ERP), Transportation Management Systems (TMS), Warehouse Management Systems (WMS) and Advanced Planning Systems (APS)*:

- ERP systems can be considered a tool that enables comprehensive planning, coordination and management of the different functions within an organisation (Nettsträter et al., 2015; Cheng, Law, Bjornsson, Jones, & Sriram, 2010). ERP systems offer tools to companies to assist and share financial processes, accounting, manufacturing and controlling (Nettsträter et al., 2015).

- On the other hand, TMS systems were developed to aid logistical distributors when dealing with increasingly complex transport chains of products/materials. TMS systems focus on providing planning, control, monitoring, and optimisation of complex distributions within supply chains (Nettsträter et al., 2015).

- Conversely, WMS systems focus on providing control and monitoring of the inventory and movement of the products/materials stored in warehouses within a company, through specific software (Ramaa et al., 2012).
- Lastly, APS systems were developed to address the limitations that the ERP systems face, such the logistical planning functionalities within organisations. APS systems enable integral, optimised and hierarchical planning structures for the supply chain, through cross-chain collaboration.

These logistic systems are usually internally used per company, and can be connected through supply chain management alignments. An overview of key and extended functionalities of the ERP, WMS, and TMS systems is provided in Appendix B-4.

5-2 The circular control environment within the Dutch building industry

The need to shift towards a circular economy is becoming increasingly important as resource scarcity increases. Many new tools have been developed from a technological perspective, to deal with these new challenges and help transition towards a more circular environment. For example, Material Flow Assessment (MFA) is one of the many concepts enabling a transition towards a circular environment, using measurements of in- and outflows of materials (Korhonen, Von Malmborg, Strachan, & Ehrenfeld, 2004). However, circular resource flow systems usually imply higher levels of complexity, due to organisational levels reaching higher interactive levels (Geldermans, 2020). Furthermore, due to the the ever-changing environment and the complex integration between contextual factors, such as economic, social and technical, these tools are becoming obsolete faster than expected (Vernay, 2013). According to Parchomenko et al. (2019), this is due to the metrics of resource productivity and efficiency not satisfying the requirements of a circular environment. This dissatisfaction is aligned to the misconception that more is produced from less input. In fact, the core concept of a circular economy implies that the value of products and materials need to be maintained over a maximum period of time (European Commission, 2015).

The development of circular building tools can be considered uncoordinated; a large number of tools are being delivered to the market simultaneously. This raises confusion among stakeholders in the construction industry (Cambier, Galle, & De Temmerman, 2020). Before developing other tools that facilitate circularity, it is important to first understand the metrics of existing tools, as these tools could facilitate particular aspects of the Modular Circular Supply Chain Model (MCSCM).

To select the most relevant tools for this thesis a list of criteria is composed, see Table 5-1. These criteria are adopted from the research of Cambier (2020), where they identify tools that support circular design processes. The first criterion is "relevant to the Dutch context", as this thesis concentrates on the Dutch context. Furthermore, this thesis focuses on the concept of

Table 5-1: Selecting criteria of circular tools (adapted from Cambier, 2020, p.3)

	Adopted criteria	Cambier's Criteria
(1)	Relevant to the Dutch context	Relevant for the Flemish building sector
(2)	Claim to support circular building	Claim to support circular building
(3)	Applicable and available for use	Available for use
(4)	Address different building phases	Address building designers and advising engineers

circularity; therefore, it is crucial that the tools analysed "claim to support circular building". Next, the criterion of "applicable and available for use" is important to include, in order to identify the tool's shortcomings and limitations based on practical applications. Lastly, it is necessary to identify tools that oversee the different phases of the building process. Consequently, the last criterion is formulated as "address different building phases".

The research is done based on different papers, reports and websites, which led to the identification of 32 circular building tools that satisfied the aforementioned criteria, see the non-exhaustive list in Table 5-2. Each tool was analysed based on their indicators and measurability of circularity. For a brief description of each individual tools please see Appendix B-3.

Table 5-2: A non-exhaustive list of circular building tools used in the Dutch context

Tool	Active since	**Number of indicators**	**Measurability/ Scaling/ Normalisation**	**Source**
Building Circularity Index (BCI)	-	2 indicators	Material index: 0-100% Detaching index: 0 - 1	(Alba Concepts, n.d)
Circle Assessment	2018	7 indicators	A+ to D	(Circle Economy, 2018)
Circular Building Assessment (CBA)	2018	1 indicator	0-100%	(BAMB, 2018)
Circular IQ Transition Indicators (CTI)	-	3 indicators	0-100% & Low to High	(Circular IQ, n.d)
Circular Design Guide	2018	4 indicators	Strategic Value	(The Ellen McArthur Foundation, 2018)
Circular Economy Index (CEI)	2015	1 indicator	Economic value	(Di Maio, Rem, et al., 2015)
Circularity Calculator	2017	4 indicators	0-100% in cycles: manufacturing, refurbishment recycling	(IDEAL&CO Explore BV, 2017)
Circularity Check	-	5 indicators	0-100%	(Ecopreneur, n.d)
Circulator	-	4 indicators	Strategic value	(EIT RawMaterials, n.d)
Circulytics	2019	2 indicators	A to E	(The Ellen McArthur Foundation, 2019)
Closing the Loop by Design (CLD)	2018	4 indicators	Set of design guidelines per indicator	(Remeha B.V., 2018)
Dutch Property inspections	-	1 indicator	Economic value	(Dutch Property Inspections, n.d)
Eco-Cost Value Ratio (ECR)	2016	1 indicator	Economic value	(Scheepens, Vogtländer, & Brezet, 2016)

Gebruikte BouwMaterialen Marktplaats	2013	2 indicators	Reuse value	(Gebruikte Bouwmaterialen B.V., 2013)
GPR Gebouw	-	5 indicators	1 to 10	(GPR gebouw, n.d)
IMPACT	2019	3 indicators	Economic value & Environmental value	(TNO, 2019)
Insert Marktplaats	-	3 indicators	Reuse value	(Insert, 2020)
Life Cycle Vision	-	4 indicators	Economic value	(Life Cycle Vision, n.d)
Madaster Circularity Indicator	2017	2 indicators	0-100%	(Madaster, 2018)
MarketplaceHUB	-	1 indicator	Other websites & Case studies	(World Business Council for Sustainable Development, n.d)
Material Circularity Indicator (MCI)	2015	1 indicator	0 - 1	(The Ellen McArthur Foundation & Granta Design, 2015)
Material Reutilization Score (MRS)	2016	1 indicator	(lowest) Bronze: ≥ 35 (highest) Platinum: 100	(Braungart & McDonough, 2009)
Milieuclassificaties Bouwproducten	2019	2 indicators	1(a) to >7(c) class	(NIBE, 2019)
O-Prognose	-	1 indicator	Economic value	(Spacewell, n.d)
Optimal SCANS	2016	5 indicators	0-100%	(Planet, n.d.)
Platform CB'23	2018-202[illegible]	7 indicators	Guidelines	(Platform CB'23, 2018)
Product Level Circularity Metric (PLCM)	2017	1 indicator	0 - 1	(Linder, Sarasini, & van Loon, 2017)
PRP	-	3 indicators	Strategic value	(Rendemint, n.d)
ReCiPe method	2018	2 indicators	(years) & (species x year) & (dollars)	(RIVM, 2018)
Recycling Index (RI)	2016	2 indicators	0-100%	(van Schaik & Reuter, 2016)
ReNtry	2016	2 indicators	Weight scale (kg)	(Rendemint, 2016)
Value-based Resource Efficiency Indicator (VRE)	2017	1 indicator	Economic value	(Di Maio, Rem, Baldé, & Polder, 2017)

5-2-1 Categorising circular building supporting tools per purpose

In the desk study the tools from Table 5-2 are categorised based on their purpose, see Table 5-3. During the desk study, it became clear that most of the tools use a combination of qualitative and quantitative indicators to estimate circularity. Furthermore, some of the supporting tools focus on a single dimension of CE, while others focus on multiple dimensions. In addition, during the analysis similarities on their utility purpose came forward. To reflect on these similarities, the tools are clustered in eight categories based on their purpose:

- **Circular business model**: many companies have recognised the importance to shift from a linear model towards a circular one. This requires them to start changing their business models towards strategies that will help this transition. In recent years, different business models have been developed to support these changes. Circulator by EIT RawMaterials is just one of these tools that supports interested parties to make conscious choices towards circular business strategies, value network strategies, and material management strategies.
- **Circular design strategy:** these tools focus on providing guidance on alternative design options that align with CE principles. The Ellen McArthur "Circular Design

Guide" tool tries to create a new mindset for companies towards circular design strategy options. On the other hand, the “Closing the Loop by Design" developed by Remeha B.V. introduces 36 guidelines for circular design strategies, addressing four components (architecture, component, connection, and materials).

- **Circularity score (organisation & material):** the tools in this category try to objectify circularity by providing scoring systems to evaluate the circular performance of the building or the organisation itself. For instance, the GPR gebouw tool evaluates five themes (energy, environment, health, quality and future value) on a scale from 1 to 10. However, it is also noticed that tools are being developed to measure the circularity level of companies themselves. For example, the CTI tool with its transition indicators, or the Circle Assessment tool with its seven categories, provide systems to assess the operational aspects of companies and often provide guidelines to transition towards a more circular economy. The way CE is scored differs per tool, because each has their specific indicators, themes and aspects.
- **Circular procurement & tendering:** this category was noticed in only one of the tools investigated in Table 5-2, the PRP tool by Rendemint. This tool takes a step further in the circular process by addressing the process of purchasing. It aims to create responsibility towards stakeholders when purchasing materials or products by making them conscious on the impact of their choices (Rendemint, n.d). Within the circular procurement process products can be purchased in a circular manner, regardless the circularity of the product (Rendemint, n.d).

Table 5-3: Categorising tools that support circular economy based on their purpose

Category	Sub-category	Tools	Code
Circular Business Models	single tool	Circulator	(A1)
	single tool	ECR	(A2)
Circular Design Strategy	single tool	Circular Design Guide	(B1)
	single tool	CLD	(B2)
Circularity Score	Material Scores	CBA	(C1)
		Circularity Calculator	(C2)
		Circularity Check	(C3)
		GPR Gebouw	(C4)
		PLCM	(C5)
		Recycling Index	(C6)
	Organisational Scores	Circle Assessment	(D1)
		CTI	(D2)
		Circulytics	(D3)
		Optimal SCANS	(D4)
Circular Procurement & Tendering	single tool	Life Cycle Vision	(E1)
	single tool	PRP	(E2)
	single tool	Optimal Scans	(D4)
Envionmental Impact	LCA	ECR	(A2)
		IMPACT	(F1)
		ReCipe method	(F2)
	MFA	MCI	(G1)
		VRE	(G2)
Extending Service-Life	single tool	Dutch Property Inspections	(H1)
	single tool	O-Prognose	(H2)
Practical Platforms	single tool	MarketplaceHUB	(I1)
	single tool	Platform CB’23	(I2)

Product/Material Assessment & Choice	New Material Platforms	BCI	(J1)
		CEI	(J2)
		Madaster Circularity Indicator	(J3)
		MRS	(J4)
		Milieuclassificaties Bouwproducten	(J5)
		ReNtry	(J6)
	Reused Material Platforms	Gebruikte Bouwmaterialen Marktplaats	(K1)
		Insert Marktplaats	(K2)

- **Environmental impact:** This category consists mainly of tools that address Life Cycle Assessment (LCA) and MFA methods which are known to focus on assessing the environmental impact. There is a wide range of tools developed, all respective to the main elements of these methods. The ReCiPe tool focuses on translating emission levels into scores based on two factors: midpoint and endpoint indicators. Midpoint indicators focus in addressing individual environmental factors while endpoint indicators deal with higher aggregation areas of protection, such as effect on human health, biodiversity and resource scarcity. (RIVM, 2018).

- **Extending service-life:** Maintenance is a crucial element to circularity as it prolongs the life and value of products and materials that a building holds. The aim of these tools is to provide long-term maintenance services for existing buildings in order to prolong the life-cycle of buildings. For instance, "Dutch property inspections" is a company that focuses on creating these multi-year plans for different types of properties (Dutch property inspections, n.d). The process starts by first identifying any past or future problems related to the building, based on the available documentation in the municipal archives. Then, a timeline and cost estimate is formulated for the inspections, structural/technical maintenance or replacement activities that need to be done. A software tool like "O-Prognose", developed by Spacewell assists companies like "Dutch property inspections", in drawing up multi-year maintenance plans.

- **Practical platform:** the collected knowledge Platform CB'23 falls under this category. It was initiated by the Rijkswatersaat, Rijksvastgoedbedrijf, de Bauwcampus and NEN for the purpose of reaching agreements for the creation of a circular construction sector. The platform aims to create a set of working agreements for the whole construction sector in order to provide some type of standardisation in regards to CE. However, these are considered more as guidelines rather than formal standards (Platform CB'23, 2018).

- **Product/Material assessment & choice:** within this category two sub- category is identified: (i) new material platforms and (ii) reused material platforms. In the case of "Reused material platforms, platforms such as Gebruikte Bouwmaterialen collect materials from buildings which are then assessed on their level of reuse and are put on a website to be sold and reused in other building sites. On the other hand, the new material platforms sub-category do not focus only on reused materials and products, but also new materials by assessing them based on various indicators. For example, the MRI tool assesses their products/materials based on their performance in regards to health, re-usability, renewable energy and carbon management, water stewardship, and social fairness. At the same time, BCI or Madaster assesses real estate objects and generates material passports, which clarifies the origin, the waste scenario, the degree of ability to separate from other materials and other characteristics in regards to these objects.

5-3 Synthesis of Circular Building Tools

To support the construction sector in its transition to a circular economy, many circular building tools have been developed, as seen in Table 5-2. According to Cambier et al. (2020), this development is uncoordinated and individual, making the application in practice difficult. Although there is an ongoing supply of such tools, the Netherlands still has a long way to transition towards a circular economy. The tools are used by different companies and stakeholders, which could result in different impacts. However, the many similarities of the tools raises the question on how efficient and effective they are in assisting the theoretical framework. Therefore, it is important to confront these tools with theory, in order to identify any limitations that these tools face.

When confronted with the theoretical production (Table 5-4) and organisation environment (Table 5-5) several conclusions have been identified:

(i) based on the information collected on the addressed circular building tools, it seems that from 32 tools, only five tools obtain the ability to collaborate with other software tools. It is observed that the majority of tools collaborate with the Madaster platform or with LCA applications. This results in many tools to either be dismissed or only being used individually by businesses.

(ii) The majority of the tools enable information exchange and direct interactions, facilitating internal coordination of the company. Thus, they focus on the internal alignments of businesses rather than external coordination of stakeholders.

(iii) None of the 32 tools integrate logistical processes, but instead attempt to facilitate innovative product design. This is achieved by providing design strategies like Circular Design guide or estimating how circular some materials are through materials scores.

(iv) The reverse loops seem to be more widely supported by the tools. However, it should be noted that the tools only provide estimations on the materials and products whether their performance allows reuse, re-manufacturing or recycling.

(v) The tools help in the internal alignment within the company borders and also support these activities, by assisting in the evaluation or advise of strategic implementations.

Table 5-4: Reflecting on circular building tools with theory (Production environment)

		Production environment		
Tool List		**Coordinate circular production processes and operations?**	**Facilitate reverse loops?**	**Advise and facilitate circular strategies?**
(A1)	Circulator	Internal business coordination	-	Supports companies in making strategic choices
(A2)	Eco-Cost Value Ratio (ECR)	Internal business coordination	-	Provides quantitative evaluations over business processes

Table 5-4 continued from previous page

		Production environment		
(B1)	Circular Design Guide	Internal business coordination	-	Suggest design strategies
(B2)	Closing the Loop by Design (CLD)	Internal business coordination	-	Suggest design strategies
(C1)	Circular Building Assessment (CBA)	Internal business coordination	-	-
(C2)	Circularity Calculator	Internal business coordination	Provide information on return/recycle possibilities	-
(C3)	Circularity Check	Internal business coordination	-	-
(C4)	GPR Gebouw	Internal business coordination	-	-
(C5)	Product Level Circularity Metric (PLCM)	Internal business coordination	-	-
(C6)	Recycling Index (RI)	Internal business coordination	Provide information on return/recycle possibilities	-
(D1)	Circle Assessment	Internal business coordination	-	Assists companies during strategic decision-making
(D2)	Circulair IQ transition indicators (CTI)	Internal business coordination	-	-
(D3)	Circulytics	Internal business coordination	-	-
(D4)	Optimal SCANS	Internal & External business coordination	-	Supports circular procurement of materials strategies
(E1)	Life Cycle Vision	Internal business coordination	-	Supports circular procurement strategies
(E2)	PRP	Internal business coordination	Provide information on return/recycle possibilities	Supports circular procurement strategies
(F1)	IMPACT	Internal business coordination	-	-
(F2)	ReCiPe method (LCA)	Internal business coordination	-	-
(G1)	Material Circularity Indicator (MCI)	Internal business coordination	-	-
(G2)	Value-based Resource Efficiency Indicator (VRE)	Internal business coordination	-	-
(H1)	Dutch Property inspections	Internal business coordination	Only extend building service life	Supports circular maintenance activities
(H2)	O-Prognose	Internal business coordination	Only extend building service life	Supports circular maintenance activities
(I1)	MarketplaceHUB	External business coordination	-	Provides examples of different strategy implementation
(I2)	Platform CB'23	External business coordination	-	Facilitates procurement and design strategies
(J1)	Building Circularity Index (BCI)	Internal business coordination	Provide information on return/recycle possibilities	-
(J2)	Circular Economy Index (CEI)	Internal business coordination	Provide information on return/recycle possibilities	-
(J3)	Madaster Circularity Indicator	Internal business coordination	-	-
(J4)	Material Reutilization Score (MRS)	Internal business coordination	-	-
(J5)	Milieuclassificaties Bouwproducten	Internal business coordination	-	-
(J6)	ReNtry	Internal business coordination	-	-
(K1)	Gebruikte Bouwmaterialen marktplaats	External business coordination	Provide information on return/recycle possibilities	-
(K2)	INSERT Marktplaats	Internal & External business coordination	Provide information on return/recycle possibilities	-

Table 5-5: Reflecting on circular building tools with theory (Organisation environment)

		Organisation environment		
Tool List		**Facilitate the internal alignment?**	**Facilitate collaboration with other parties?**	**Allow for information exchange?**
(A1)	Circulator	Internal business alignment	Stand-alone tool	Internally only
(A2)	Eco-Cost Value Ratio (ECR)	Internal business alignment	Stand-alone tool	Internally only
(B1)	Circular Design Guide	Internal business alignment	Stand-alone tool	Internally only
(B2)	Closing the Loop by Design (CLD)	Internal business alignment	Stand-alone tool	Internally only
(C1)	Circular Building Assessment (CBA)	Internal business alignment	Collaborate with other tools	Internally & Externally

Table 5-5 continued from previous page

		Organisation environment		
(C2)	Circularity Calculator	Internal business alignment	Stand-alone tool	Internally only
(C3)	Circularity Check	Internal business alignment	Stand-alone tool	Internally only
(C4)	GPR Gebouw	Internal business alignment	Stand-alone tool	Internally only
(C5)	Product Level Circularity Metric (PLCM)	Internal business alignment	Stand-alone tool	Internally only
(C6)	Recycling Index (RI)	Internal business alignment	Stand-alone tool	Internally only
(D1)	Circle Assessment	Internal business alignment	Stand-alone tool	Internally only
(D2)	Circulair IQ transition indicators (CTI)	Internal business alignment	Stand-alone tool	Internally & Externally
(D3)	Circulytics	Internal business alignment	Stand-alone tool	Internally only
(D4)	Optimal SCANS	Internal business alignment	Stand-alone tool	Internally only
(E1)	Life Cycle Vision	Internal business alignment	Stand-alone tool	Internally only
(E2)	PRP	Internal business alignment	Stand-alone tool	Internally only
(F1)	IMPACT	Internal business alignment	Collaborate with other tools	Internally only
(F2)	ReCiPe method (LCA)	Internal business alignment	Stand-alone tool	Internally only
(G1)	Material Circularity Indicator (MCI)	Internal business alignment	Stand-alone tool	Internally only
(G2)	Value-based Resource Efficiency Indicator (VRE)	Internal business alignment	Stand-alone tool	Internally only
(H1)	Dutch Property inspections	Internal business alignment	Stand-alone tool	Internally only
(H2)	O-Prognose	Internal business alignment	Stand-alone tool	Internally only
(I1)	MarketplaceHUB	-	Stand-alone tool	Internally only
(I2)	Platform CB'23	Internal business alignment	Collaborate with other tools	Internally & Externally
(J1)	Building Circularity Index (BCI)	Internal business alignment	Stand-alone tool	Internally only
(J2)	Circular Economy Index (CEI)	Internal business alignment	Stand-alone tool	Internally only
(J3)	Madaster Circularity Indicator	Internal business alignment	Collaborate with other tools	Internally only
(J4)	Material Reutilization Score (MRS)	Internal business alignment	Stand-alone tool	Internally only
(J5)	Milieuclassificaties Bouwproducten	Internal business alignment	Stand-alone tool	Internally only
(J6)	ReNtry	Internal business alignment	Stand-alone tool	Internally only
(K1)	Gebruikte Bouwmaterialen marktplaats	-	Stand-alone tool	Internally & Externally
(K2)	INSERT Marktplaats	Internal business alignment	Collaborate with other tools	Internally & Externally

In Table 5-6, the tools were confronted with the virtual control environment. In the analysis, it was observed that the majority of tools provide the functionality of decision making. The aim of the tools is to help companies and organisation in making more conscious decisions that align with circular principles, such as changing their business models, purchasing sustainable materials or embracing new circular strategies. As previously mentioned, the tools lack the ability to collaborate with external parties, but rather concentrate on enhancing the internal alignment of their organisation in regards to circular principles. In addition, due to the tools obtaining indicators that align with the design process none of 32 analysed tools addressed reverse logistics or planning & routing. Furthermore, the information stored in these tools, especially for the material assessments and design/procurement guidelines could be beneficial to facilitate a more circular environment. For example, providing tools to assess the circularity level of materials enables manufacturers to choose and produce innovative products that can be re-utilised, re-manufactured or recycled at their end-of-service-life. However, to conclude on which tools obtain the most relevant information and abilities to connect to a control centre, more research is needed on this specific topic.

The tools were also confronted with the social environment, see Table 5-7. At first instance, the financial, legal and cultural dimensions are not addressed in the development of these tools. Only a small number of tools address these two concepts, which according to several researches are crucial elements when dealing with the implementation of circular supply chains (González-Sánchez et al., 2020).

Table 5-6: Reflecting on circular building tools with theory (Control environment)

		Control environment		
Tool List		**Can act as a facilitator of the control environment?**	**Hold any of the functionalities?**	**Hold any of the requirements?**
(A1)	Circulator	-	Help in business strategy decision-making	-
(A2)	Eco-Cost Value Ratio (ECR)	-	Help in design decision-making	-
(B1)	Circular Design Guide	-	Help in design decision-making	-
(B2)	Closing the Loop by Design (CLD)	-	Help in design decision-making	-
(C1)	Circular Building Assessment (CBA)	-	Help in decision-making by material scores	Connect and coordinate with other tools
(C2)	Circularity Calculator	-	Help in decision-making by material scores	-
(C3)	Circularity Check	-	Help in decision-making by material scores	-
(C4)	GPR Gebouw	-	Help in decision-making by material scores	-
(C5)	Product Level Circularity Metric (PLCM)	-	Help in decision-making by material scores	-
(C6)	Recycling Index (RI)	-	Help in decision-making by material scores	-
(D1)	Circle Assessment	-	Help in decision-making by organisation score	-
(D2)	Circulair IQ transition indicators (CTI)	-	Help in decision-making by organisation score	-
(D3)	Circulytics	-	Help in decision-making by organisation score	-
(D4)	Optimal SCANS	-	Help in decision-making by organisation score	-
(E1)	Life Cycle Vision	-	-	-
(E2)	PRP	-	Help in decision-making about purchase of materials	-
(F1)	IMPACT	-	-	Connect and coordinate with other tools
(F2)	ReCiPe method (LCA)	-		-
(G1)	Material Circularity Indicator (MCI)	-	Help in decision-making by evaluating materials	-
(G2)	Value-based Resource Efficiency Indicator (VRE)	-	-	-
(H1)	Dutch Property inspections	-	-	-
(H2)	O-Prognose	-	-	-
(I1)	MarketplaceHUB	-	Pinpoint location of secondary materials	-
(I2)	Platform CB'23	Possibly	Help in decision-making about design and type materials	Connect and coordinate with other tools
(J1)	Building Circularity Index (BCI)	-	-	Connect and coordinate with other tools
(J2)	Circular Economy Index (CEI)	-	-	-
(J3)	Madaster Circularity Indicator	-	-	Connect and coordinate with other tools
(J4)	Material Reutilization Score (MRS)	-	-	-
(J5)	Milieuclassificaties Bouwproducten	-	-	-
(J6)	ReNtry	-	Help in decision-making about type of materials	-
(K1)	Gebruikte Bouwmaterialen marktplaats	-	Store information of secondary materials	-
(K2)	INSERT Marktplaats	Possibly	Store information of secondary materials	Connect and coordinate with other tools

Table 5-7: Reflecting on circular building tools with theory (Social environment)

		Social environment		
Tool List		**State any regulations?**	**Give indications on financial estimations?**	**Facilitate in the change of cultural mindset?**
(A1)	Circulator	-	-	-

Table 5-7 continued from previous page

		Social environment		
(A2)	Eco-Cost Value Ratio (ECR)	-	Provide information on material cost estimations	-
(B1)	Circular Design Guide	-	-	-
(B2)	Closing the Loop by Design (CLD)	-	-	-
(C1)	Circular Building Assessment (CBA)	-	-	-
(C2)	Circularity Calculator	-	-	-
(C3)	Circularity Check	-	-	-
(C4)	GPR Gebouw	-	-	-
(C5)	Product Level Circularity Metric (PLCM)	-	-	-
(C6)	Recycling Index (RI)	-	-	-
(D1)	Circle Assessment	-	-	-
(D2)	Circulair IQ transition indicators (CTI)	-	-	-
(D3)	Circulytics	-	-	-
(D4)	Optimal SCANS	-	-	-
(E1)	Life Cycle Vision	-	-	-
(E2)	PRP	-	-	-
(F1)	IMPACT	-	-	-
(F2)	ReCiPe method (LCA)	-	-	-
(G1)	Material Circularity Indicator (MCI)	-	-	-
(G2)	Value-based Resource Efficiency Indicator (VRE)	-	-	-
(H1)	Dutch Property inspections	-	-	-
(H2)	O-Prognose	-	-	-
(I1)	MarketplaceHUB	-	-	-
(I2)	Platform CB'23	Include regulatory requirements	-	Attempts to provide a share language in regards to circularity
(J1)	Building Circularity Index (BCI)	-	-	-
(J2)	Circular Economy Index (CEI)	-	-	-
(J3)	Madaster Circularity Indicator	-	-	-
(J4)	Material Reutilization Score (MRS)	-	-	-
(J5)	Milieuclassificaties Bouwproducten	-	-	-
(J6)	ReNtry	-	-	-
(K1)	Gebruikte Bouwmaterialen marktplaats	-	-	-
(K2)	INSERT Marktplaats	-	-	-

Overall the confrontation of the circular building tools showed that a significant number of theoretical components are not satisfied. This together with the oversupply of tools observed from Table 5-3 raises the question on which process phases are supported. In order to understand this, the tools have been appointed per process phase, see Figure 5-1. Based on this analysis, the majority of tools are being developed to facilitate three project phases; design, procurement and transforming. However, the transforming stage tools mainly provide circularity scores and assessments for materials and products that could be used in a building project.

Research identifies the need for tools to calculate a circularity score, while there are already tools available in the market that partly perform these measurements (Cambier et al., 2020). However, Idowu et al. (2013) argue that circular scores may “greenwash" the concept of CE by falsely promoting strategies and methods being circular, while they actually do not lead to circular outcomes. In addition, each of the circularity score and assessment tools have different sets of indicators, as a standard framework for circular building bench-marking is absent. Consequently, the results generated by these scoring tools might differ significantly from each other, which could lead to confusion and misinterpretation in both vertical and horizontal collaboration. Therefore, it is crucial for a standard framework to be established which could be used by score tool developers as indicators used in the measurement of circularity, simultaneously safeguarding CE from “greenwashing".

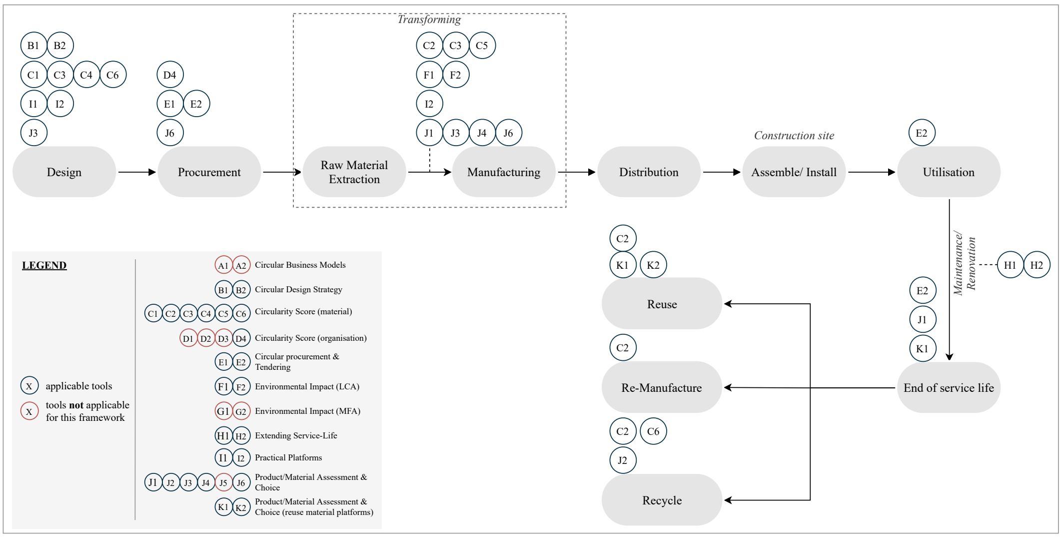

Figure 5-1: Appointing circular building tools per appropriate supply chain stage

The design tools similar to the circular scoring tools, are significantly individual and have personalised indicators and strategies for producing a circular design. There is an ongoing research being done both in practice and in academia for the development of design tools supporting circular building. According to Cambier et al (2020), most of these researches focus in either of the following areas: (i) integration of BIM and LCAs, (ii) circular design strategies and (iii) measuring circularity in a building. BIM was not considered as a tool in this research, but rather a information system, similarly to the 4C concept, that facilitates the sharing of linear information within a building project.

The circular procurement tools are fairly new in the market, and try to address the purchasing and tendering processes in a more circular manner. These purchasing activities refer both materials and actors, such as in the case of Optimal SCANS, where a measurement of the circularity level of various suppliers is calculated. Again these tools make use of quantitative methods in order to make CE more tangible.

There are also several tools that do not fit into the specific process as they are mainly representing circular measurement possibilities for organisations and companies. In addition, the tools assigned to the three levels of reverse loops (reuse, re-manufacture and recycling) are also tools that mainly measure the circularity level of products and materials that are able to be reused or recycled, which could still enable the “greenwashing" problem. There are two important tools, Gebruikte Bouwmaterialen and Insert Marktplaats that properly facilitate the reuse possibilities of the collected materials and products, by reselling them to third parties.

The development and use of circular design and procurement support tools can only guarantee the creation of a circular building. These tools can provide information on the circularity levels of materials, products and buildings, which can be beneficial for manufacturing more innovative circular products. However, there is still a large shortcoming of developed tools that address the other stages, such as distribution or utilisation. Currently, a support circular design does not guarantee for the reverse loops to be present, nor an integrated process to happen.

5-4 Reflection on key aspects of this chapter

This chapter aimed to capture empirical information on the tools and information systems currently present and facilitating the control environment of the building industry. Although the focus was toward the circular control environment, some general information systems were also recognised. The described systems in this chapter encompassed different applicability abilities in a supply chain. Systems, such as ERP and APS focus in coordinating the planning, scheduling and other activities of an organisation/company. Other systems, focus on planning logistical distribution operations, such as TMS systems, or deal with the internal warehouse operations, such as WMS systems. However, these systems have in common the lack of collaboration and coordination across one's company borders. Building Information Modelling, seems to be the only system that provides such collaboration possibilities as it provides system packages that encompass different stakeholders of supply chains. However, there are still limitations towards these systems, as they mainly are being applied in specific stages of projects and does not yet cover the entire supply chain. Furthermore, the component of real-time information seems to be the overarching limitation between all identified systems.

The continuous research and development of new tools for facilitating the creation of a circular environment, indicates that the current tools and their indicators are not satisfactory for each level of the circular context. Based on the selecting criteria, 32 different circular building tools assisting the Dutch context were identified. This shows that several actors and stakeholders are interested in the development of CE facilitating technologies. A summary table of the circular building tools, Table 5-2, was structured based on the following information: name of tool, year they became active, number of indicators, measuring/scaling/normalisation and source. In addition, each tool was in detail described (Appendix B-3), which helped in identifying some overlapping similarities and providing a categorisation of all tools. Then, the tools were confronted with theory and their current position in the circular supply chain was noted. The main result of this analysis showed that the majority of tools are being developed with the same purpose: to measure and give scores on materials or organisations themselves on how circular they are. Furthermore, these scores vary per tool, which makes comparability difficult. The absence of a standard framework of circularity indicators is a hazard in developing an integrated circular supply chain process. On top of the lack of a common language, the majority of the tools stand-alone and do not connect and collaborate with each other. If there is collaboration then it is noticed that this is mainly done with the Madaster platform and the BIM system.

The early phases of the process especially the design and transformation phase hold the majority population of the tools. However, due to the tools mainly providing a score, does not guarantee the creation of reverse loops. Furthermore, the absence of tools overseeing the legal, financial and cultural dimension and other components of the MCSC model show that a significant number of areas that theory identifies as critical for the creation of CSCs is lacking. This also raises the question of the greenwashing issue, thus no concrete actions are facilitated by these tools. The circular building tools will be further addressed in the interviews.

Chapter 6

Building Industry Case Perspectives on Circular Supply Chains

Chapter 5 provided information on the current information systems and circular building tools that are present in the market and used by different organisation types. These systems and tools will be revisited in this chapter, to identify which are mainly used by the interviewed organisations.

Part 1 of the thesis clarified the differences between the linear and circular processes. Therefore, it is important to also analyse the influences this has on the stakeholder network (Section 4-3). This section, merges information between literature, semi-structured interviews and respective documentation of interviewed organisations. Next, based on the conducted interviews the type of information required for creating a circular supply chain is addressed through the question: *How is the MCSC theoretical model perceived by organisations active in the building industry?* In addition, the variables of the MSCSM environment identified in Chapter 3 were also addressed during these interviews to capture the perceptions of the cases.

6-1 Outline of the Building Cases

In Chapter **??**, the network analysis of the building organisation environment identified the traditional stakeholders present in project processes and then their interrelationships. The analysis was conducted not only to identify the stakeholders, but also understand which organisational functions have influence in decision-making within supply chain processes. Based on these findings the cases to be interviewed were determined. The cases selected for this research were found through public information available of the organisations and by direct contact with the organisations. The cases selected have shown indications of applying circular strategies to a certain extent and by being involved in circular projects.

Although, the focus lies in the stakeholders within the direct environment, the indirect environment is also important to investigate, specifically seeing the importance of logistic providers in both traditional and circular specific stakeholders. Therefore, the cases apply to eight organisation types: municipality representatives, project developer, designer, project manager, contractor, logistic provider, supplier and dismantling/demolishing companies. In addition, the IT organisation type were also included to obtain expert knowledge on the IT functionalities that potentially a control centre should obtain. A total of 15 semi-structured interviews were conducted, divided over the organisation types that have direct and indirect involvement in the project environment, see Table 6-1.

Table 6-1: Interviewed organisations

Building Cases	**Organisation Representatives**
Municipality	Municipality of Amsterdam (Deputy Program Manager Circular Economy)
Municipality	Municipality of Utrecht (Circular Economy developer, financial team)
Project developer	Re:Born real estate
Project developer	AM | Inspiring Space
Project manager	Utrecht Sustainable Institute
Project manager	Dutch Green Building Council
Design experts	Platform CB'23 (circular design action team)
Contractor	Dura Vermeer (Building & Real Estate B.V. division)
Contractor	Heijmans (energy & sustainability division)
Supplier	Chainable B.V.
Logistic service provider	Timmers. Practische Bouwlogistiek
Dismantling/demolishing companies	New Horizon (Material Balance collective)
Dimantling/Demolishing companies	Beelen (Beelen Next division)

It should be noted that the cases do not represent a particular building project supply chain. However, they collectively provide an overview of the different parts of the supply chain, and the derived findings allow to capture their perception on a circular supply chain environment facilitated by a control environment.

6-2 Organisation of building case description

Each of the case studies starts by giving a general introduction to the particular organisation representative. The interviews were transcribed and analysed based on the eleven analysis variables identified within the four theoretical framework areas: (i) production environment (ii) organisation environment, (iii) control environment, and (iv) social environment. The description maintains the data collected in interviews but also secondary documentation relative to the organisation representatives. Each of the cases starts with a short introduction of the particular company. Then a descriptive summary is provided through the eleven variables, which are also illustrated by representative quotations from the interviews. Depending on their organisation type, the cases address the various components differently, posing a challenge to the translation in a functional design.

In order to enable the comparison in the within- and cross-case analysis, the descriptions and tabular overviews have been presented in a similar way.

6-3 MCSCM Environment Perception | Municipality

Governmental bodies, in this case municipalities of two large Dutch cities, have influence into the fiscal and regulatory environment of the project. Dutch municipalities often operate in different levels, such as by having an active and dominant role in the development of urban planning (Heurkens & Hobma, 2014). However, this role has shifted towards a more facilitating one due to the active land development leading towards financial losses. This means that the private sector is required to take an active and leading role in the development processes (Heurkens, 2013).

Dutch municipalities are large organisation formations that include different departments. For this thesis two representatives from two different municipalities were chosen that have knowledge on the built environment and are researching or taking initiatives towards the establishment of a circular economy. These are professional workers who are not politically driven and mainly deal with the technical and administrative activities. They will be referred as Municipality A and Municipality B. The reason for choosing two different municipalities, is to identify whether there are any differences or similarities in the municipality approaches.

6-3-1 Production environment

Operation and process coordination

The operation and process coordination of municipalities depends on the role that these municipalities have on certain projects. Both municipalities mainly have influence on the public space, rather the building project itself, due to not being owners of the land. This gives them minimal direct influence into the building project. Thus, in order to coordinate their ambitions and processes they rely on the operation between four roles: (i) shaping, (ii) regulating, (iii) capacity building and (iv) stimulating. Within each of the roles there are certain activities present, which encompass their internal processes, see Figure 6-1

The process and operation coordination of both municipalities is achieved through master plans, zoning plans or other regulations depending on the role approach. For instance, Municipality A organises the tenders for its own real estate and specifically public space and tenders for land allocation that are aligned with circular principles. Sometimes this requires the adjustments of some internal processes. Furthermore, Municipality B also addresses the initiations of establishing processes that can help the general coordination of construction projects. An example is the initiation for a national fund for the creation of database holding a list of publicly accessible examples of circular building projects. Such initiation is expected to stimulate and support market parties that want to built circular but do not know how.

> "*The municipality organises the tenders for its own real estate, public space (both above and below ground) and tenders for land allocation in such a way that it becomes circular, for example by organising the current internal processes differently where necessary.*" — Municipality A, personal communication, April 20, 2021)

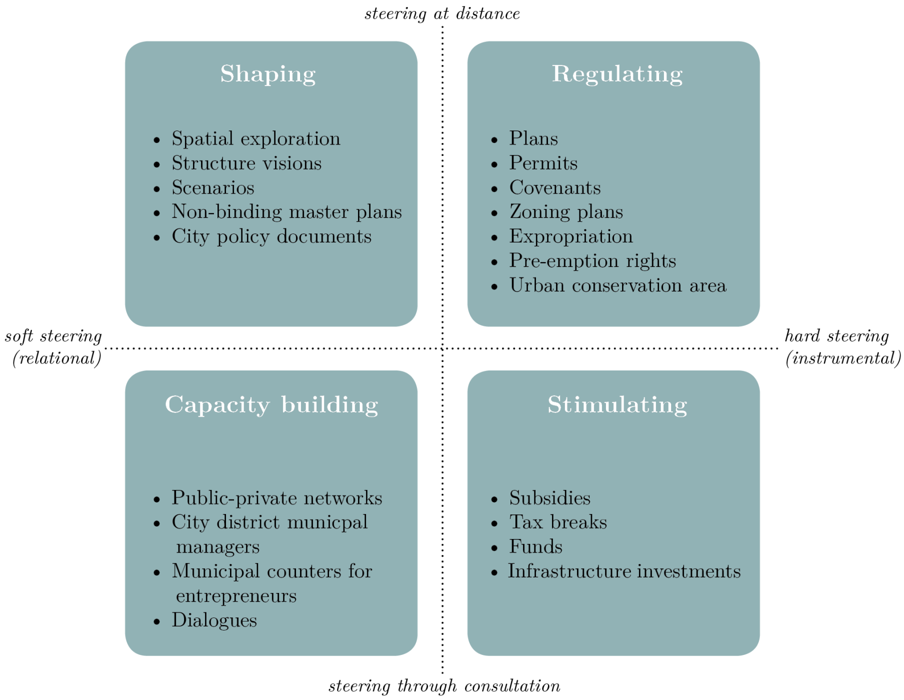

Figure 6-1: The four municipal operating roles

Circular reverse loops

Reverse loops were understood by Municipality A as the consideration of all building processes in an integral way. The linear line is now considered as a circle, in which once the building reaches its end of service life is disassembled and the products are transported to locations in which they are prepared for other uses. In regards to stakeholders, Municipality B identifies the role of demolishing companies as crucial for this dimension to happen. In addition, Municipality B argues that the systems thinking is significantly dominated by a reactive mindset.

> "*The systems thinking is reactive, meaning that the process starts with initiation phase, and design phase. Once these are done then the construction phase begins and the thinking and planning from the firm starts about the organisation of built and logistics. This was logical in the past, but it is not anymore for the future.*" — Municipality B, personal communication, April 16, 2021)

The municipality organises the collection of waste and raw materials and attempts to establish circular hubs. However, companies themselves are responsible for separating and disposing their own industrial waste. Lastly, the gained knowledge is made publicly available for social institutions, especially schools in order to inspire more companies and people.

Strategy integration

Municipality A states that circularity is about maintaining and adding value, and operating in a collaborative way. In addition, strategies are undertaken that enhance building in a circular way and avoid unnecessary construction projects by utilising vacant spaces in the existing built environment. However, this requires transparency and information exchange. Furthermore, Municipality B emphasises the need to minimise the footprint by eliminating waste. A circular supply chain is seen as the process that extends from one to multi life-cycles. Both municipalities are taking initiative to study and initiate more circular processes within the built environment. It is observed that these strategies take the shape of regulations and guidelines that support the circular process strategies which narrow, slow-down or close resource loops. More detail on these specific strategies are described in the 'social environment'.

> "*Circularity to us is all about maintaining value. If you deal with all the elements individually, it is not possible to optimise. (...) For example, when you have two office buildings along a street where one office building is fully occupied but the other has vacant spaces then it is not necessary to build a third office building, because you can utilise that vacant space. That is also the type of circularity we look for.*" — Municipality A, personal communication, April 20, 2021)

> "*Circular economy is a system in which we make products and buildings in a smart way, which can be repaired and have a higher life-span. Nothing has to be thrown away or even incinerated. It is also a system in which we make better use of human capabilities, by engaging them during the building process.*" — Municipality B, personal communication, April 16, 2021)

6-3-2 Organisation environment

Internal alignment

Traditionally municipalities focus all their internal alignments towards the serving the public interest and providing a healthy built environment. To achieve their main role to serve the public, the internal alignment of municipalities cover several various topics. For the purpose of this thesis the internal alignment towards the development of a circular environment is taken into account.

Municipality A are active and stimulating the market towards circular innovations, by establishing frameworks to give direction to themselves and to the market parties. In recent years, the importance of creating a circular built environment has been observed. Therefore, several internal researches are conducted from which a set of ambitions to support this topic. The circular approach encompasses not only the built environment, but also about food and consumption of goods. The ambitions are still fairly qualitative and are still being developed in order to translate them in a quantitative way. Currently, they act as a to do list for the internal alignment of the municipality.

Similarly, Municipality B also has identified the importance of a circular environment. Thus, in the last years researches has been conducted to clarify their ambitions internally. The current circular approach is mainly aimed at the built environment. Thus, the inner-city housing assignment is of great importance for the circular ambition. The internal alignment is focused in developing more concrete steps towards the creation of a waste-free construction process and economy.

Cross-chain collaboration

The external collaboration of the municipalities is identified in two areas: within projects or with external companies with the help of agreements or deals. First, within building projects with the stakeholders of the supply chains. Municipality A argues that although the collaboration is significantly high due to being involved in the same building project, the competitive environment is still notable together with the culture of mitigating responsibility away. Municipality B also has intensive internal municipal cooperation and in collaboration with the involved market parties of a project to understand to what extent circular ambitions can be achieved.

In addition, both municipalities have also collaboration with knowledge parties or are involved in various deals, such as the case of Municipality B with the City Deal or Green Deal Circular Purchases. Municipality A has selected a set of future partners (companies, knowledge institutes and municipal departments) depending on the strategy ambitions.

> "*Although there's a lot of collaboration, because of working together on a building, there is also a lot of competition. In addition, often contracts are based on pushing responsibility away. Thus, it would be interesting to investigate and implement a collaborative responsibility.*" — Municipality A, personal communication, April 20, 2021)

Information exchange

Both municipalities are transparent and already share the majority of their information. This is due to their position in handling the public finances. According to Municipality B, the willingness to share information is noticed to be fairly high especially with front-runner companies in regards to circularity. However, an increase of interested is also noticed from other market companies due to the procurement and tendering processes.

Some general information systems used by the municipalities are MOCO, which holds mainly traffic information. Next, VICTOR is another information system used specifically to hold the building permits of the different construction projects. Both municipalities have a lot of data stored in their information systems, in which all articles, zoning plans or master plans and other maps and documentation that are stored.

> "*An initial conclusion is that it is important to have information on the product and material flows in the chain, where they currently are present in the chain and who is responsible for them.*" — Municipality A, personal communication, April 20, 2021)

> "*Since 2016 the willingness of sharing information with the circular front runners is huge. This is also observed with the overall interest of companies on the topic is growing, but slowly. (...) There is a lot of information available, in the form of single publications and PDFs, really good study examples. But the information sharing is lacking. Thus, with public money, we should be much more efficient to make a database of the actual transcending circular buildings and projects, that encompass the building sector and also other sectors, which need a very different approach and have a very different involvement of parties and investment decisions*" — Municipality B, personal communication, April 16, 2021)

Table 6-2: Overview of case findings (Municipality)

Analysis Variables	Description per case	
	Municipality A	*Municipality B*
Production environment		
Operation and process coordination	Organise tenders of own real estate and especially public space. Willing to adjust internal processes to include circular principles.	Coordinate the processes by including circular requirements in tenders, and initiating funds and subsidies to facilitate more circular building.
Circular reverse loops	The linear line is considered as a circle, that once the building reaches its end of service life is disassembled and the products are transported to locations in which they are prepared for other uses. Stakeholders: Bringing to the table more stakeholders in an integrated way. Information: Aim to establish circular hubs and organise the collection of waste.	Changing from a reactive mindset to a proactive mindset. Stakeholders: Demolishing companies are considered as crucial actors in reverse loops. Information: Aim to establish material passports for each construction building.
Strategy integration	Circularity is understood as the maintaining/ adding value and operating in a collaborative way.	A circular supply chain is seen as the process that extends the life-cycle of products/materials and the minimisation of the footprint by eliminating waste.
Organisation environment		
Internal alignment	Creating a set of circular ambitions that encompass three areas, among others the building industry.	The internal alignment towards the circular approach is mainly aimed at the built environment and how to provide regulations and incentives to facilitate them.
Cross-chain collaboration	Have established collaborations regionally: with companies, knowledge institutes and municipal departments, locally: with the companies involved in a construction project and nationally within deals and agreements.	Have established collaborations regionally: with companies, knowledge institutes and municipal departments, locally: with the companies involved in a construction project and nationally within deals and agreements.
Information exchange	Transparent and willing to share information is high due to their position. Barriers of information exchange: Information availability is not equal from all parties. Information system: Use of MOCO, VICTOR and other information systems that hold maps and documentations, like master/zoning plans.	Transparent and willing to share information is high due to their position. Barriers in information exchange: A higher willingness is noticed from circular front-runners to share information rather than traditional companies. Information system: No specific information system identified, but the systems hold maps and documentations, like master/ zoning plans.
Control environment		
ICT architecture requirements & functionalities	Safe and secure system; Data exchange through a set of filtering; Publicly accessible from everyone, but with some filtering layers.	A common system language that allows for data exchange.
Control facilitators across supply chains	Suggestion to have it not controlled from a human, but rather from communication between systems	No specific facilitator was recorded.
Circular building tools	Use of Circularise, Insert platform and Circular IQ.	No specific tools were recorded.
Social environment		
Legal, financial & cultural	Legal: Changing regulations on the MPG calculations. Financial: Provides financial incentives to support businesses that undertake circular building projects. Cultural: Difficulty in changing the mindset of people. Taking actions by investigating the circular building tools and trying to establish a common language.	Legal: Making performance agreements with housing corporations for circular renovations and overall construction; Including circular criteria into the procurement and tendering processes. Financial: Provides financial incentives and instruments to support businesses that undertake circular building projects. Cultural: Taking a proactive approach to create a circular built environment. Publishing information over finished circular projects, to act as examples and inspiration.

6-3-3 Control environment

ICT architecture requirements & functionalities

The major functionality identified by both municipalities related to the information sharing possibilities. It was argued that data needs to be easily exchangeable between the different systems that various stakeholder use. In addition, Municipality A emphasises the need to implement certain filter options to this exchange of information, in order to maintain some critical information confidential an share what is most needed. Thus, the control environment should be a safe and secure system. In addition, Municipality B addresses the importance of having a common language for the system, in order to make the data easily exchangeable.

> "*For example, 10 years ago, I was busy with the biking infrastructure and an app was being used. Thus, if one is biking outside and there is a light and it's broken, one could through the app make a ticked that notifies the municipality to fix this issue. However, it was noticed that the language of those apps didn't interact with the ICT of the municipalities. Therefore, we should pay extra to integrate those signals, or for repairs into our information systems. It is a pattern that often is visible in the market, where you have innovations developing an own language, and part of the business model is exclusion of other languages. And then 10 years ago, big municipalities decided, to make a so-called Esperanto language. Thus, if one is using a certain set of parameters, then business can be done. This can enable an investment horizon: to make decisions and scale up your investments in development.*" — Municipality B, personal communication, April 16, 2021)

> "*Different parties are developing different programming languages in which to make steps in this, one should be clear about the tangibility and minimum standards of the language.*" — Municipality B, personal communication, April 16, 2021)

Control facilitator across supply chains

Municipality A provides the suggestion of the control environment not being controlled by a human facilitator, but rather be a connection of the different tools and systems, which allow data to be exchanged and accessible by different people. No specific facilitator was recorded in the interview with Municipality B.

> "*The question is if 'someone' should be in charge of controlling, but rather an entire process. Maybe a blockchain type of solution could facilitate the information to go from one phase to the next without losing important information or it being altered and giving access to stakeholders.*" — Municipality A, personal communication, April 20, 2021)

Circular building tools integration

As a representative mainly focusing on the administrative functionalities, Municipality A made use of a few circular building tools during their operations. Among others, the Circularise tool and the Insert platform was highly used internally. However, other tools present in the market are also reviewed, such as Circular IQ, specifically for circular purchasing possibilities. According to Municipality A, it is understood that developing tools and up-scaling them is difficult form a technical and financial point of view, although up-scaling is important.

> "*We try to analyse everything that is being developed, to understand what is in the market. We are also participating in a digital design challenge, which is a open call to all software developers that could bring new solutions. What we see from this process is that it is hard to develop a product and up-scale it.*" — Municipality A, personal communication, April 20, 2021)

6-3-4 Social Environment

Legal, financial and cultural factors

From a *legal perspective* Municipality B has been taking concrete steps towards the implementation of circular building. For instance, performance agreements are made with housing corporations in regards to circular renovations and construction. In addition, it has been suggested and it is being investigated on lowering the limits of the MPG calculations from 1 to a 0.5. This is also an ambition for Municipality A. Procurement and tendering are other fields of attention, in which more circular criteria are being included. These requirements are not only for the municipality themselves but also applicable to market parties.

From a *financial perspective* both municipalities have a limited circular budget and capacity. Therefore, attention is put towards initiatives that implement circular strategies. In addition, Municipality B is investigating possibilities to strengthen the investment climate in the region to assist innovative companies. The ambition is to improve the set of economic instruments to focus entirely on companies and projects with a significant contribution to social tasks, including circular building. Municipality A also provide positive cost incentives, such as subsidies to businesses to financially support their initiatives towards circular building.

> "*There needs to be some financial assistance or benefits for the companies that are initiating circular building. If you look into rvo.nl, especially into the fiscal investments for specific topics. It is possible to get substantial benefits, which have effect and may change the investments decisions of companies.*" — Municipality B, personal communication, April 16, 2021)

From a *cultural perspective*, Municipality A addresses the difficulties encountered towards the mindset change of people. This is visible from the gap between the number of buildings that are still constructed in a traditional manner compared to the number of circular building. To help facilitate a common language and standard tools regulations are considered as a potential solution. Therefore, the municipality is constantly analysing the circular building tools that are being introduced in the market and potential agreements that could be made. Furthermore, Municipality B adds also the importance of taking a proactive approach in cooperating with educational institutions, which help share information and knowledge, thus aiding to the change of mindset. Examples of finished circular projects are thought to be important for this purpose. Lastly, Municipality B is also attempting to attract more circular innovative companies into their region, to facilitate this change of culture.

> "*It is difficult to change people's behaviour, and establish a similar way of working with similar tools and agreements. For that, it would help if there were rules and regulations. Although I'm not saying that there should be.*" — Municipality A, personal communication, April 20, 2021)

6-4 MCSCM Environment Perception | Project Developers

Project developers can be understood as private client organisations, which play a primary role in construction projects having strategic, and operational responsibilities. In addition, the influence on project decision-making moments is demonstrated through setting project scope, character, financial details and design requirements (Chinyio & Olomolaiye, 2009). In this case two developers from different organisations were interviewed, that are involved in initiating circular projects, see Table 6-3 for an overview of the findings.

Developer A mainly operates on residential areas, offices, shopping centres and leisure facilities. In the last couple of years, this developer has been focusing in strengthening its position into topics, such as sustainability, circularity, health and mobility.

Developer B was originally founded with the circular principles in mind as a result of the large number of vacant buildings. The company currently focuses in (re-) developing existing buildings into flexible buildings. To ensure flexibility, the company focuses in developing buildings and areas that continuously respond to the operational, technical and other societal demand changes. Thus, providing the building a new service-life in the supply chain cycle.

6-4-1 Production environment

Operation and process coordination

Usually, the developer coordinates all the processes starting from the design to the construction of the building. Thus, overseeing the development of the entire real estate project process. In some instances it is noticed that developers also internalise operations and processes, such as the concept development and design (Developer A), or investing their own projects (Developer B). In addition, the processes are aligned to achieve the five principles.

> "*The developer connects all the dots as we find the client, the location, the building; we manage the money and the parties. Thus, everything from A-Z.*" — (Developer B, personal communication, April 8, 2021)

Circular reverse loops

During the interviews the developers where questioned on the perception and what is needed for reverse loops to be established. Developer A argues that for reverse loops to exists, informaiton is required on the type of materials that are available to be re-purposed. On top of this, both developers agree that the details of these materials need to be accessible by all stakeholders to ensure and guarantee that the material is suitable for a new project. This detailed information could be provided through a material passport. Developer A also suggests that new stakeholders should be introduced into the process, such as a reclamation expert.

> "*To make the return loop happen, you need to know what materials are available. A reclamation expert will be a new function. We now have a team, such as a constructor, architect and so on, and in the future, we also will need a reclamation expert, who will find the materials to be (re-)used in the building.*" — (Developer A, personal communication, April 28, 2021)

Developer B argues that reverse loops are initiated through transformation processes. Transformation process are often initiated by a big team, like structure engineers, architects, building service engineers and managers, that focuses in analysing the existing building layers. This is different from a new-built project, which is initiated in a more linear way and stakeholders are involved in different stages of the process.

> "*The biggest difference between new buildings and transformations is that in transformations you start with a big team that analyzes the building; with structure engineers, architects, building surface specialist, managers and so forth. Whilst, in a new development, you start with an architect, who makes drawings and experts are involved after the design is finished. Step by step you get more experts on board, which is a more linear approach.*" — (Developer B, personal communication, April 8, 2021)

Strategy integration

Both developers are interested in the implementation of circularity into their projects. This is done based on their own principals and objectives, discussed in the 'internal alignment' section. According to Developer A, usually a linear construction economy is based on transaction and it significantly vulnerable to economic crisis or pandemics. Often profits are only achieved once the building is sold, while a circular economy is seen to provide a steadier cash flow, as the building components are turned into services that would be leased, making one less vulnerable to economic crisis. In addition, a circular supply chain seems to bring benefits towards the environmental dimension as it allows for products and materials to be reused within the cycle.

> "*We did an online training with Ellen MacArthur Foundation and that was an eye-opener about circularity and the economic aspects of it. (...) If you have a circular business model, where you get paid for your service, every month or every year, bringing your company constant cash flow makes you less vulnerable for economic crisis.*" — (Developer A, personal communication, April 28, 2021)

Developer B adds to the vision of circular supply chains a distinction between new-built projects and transformation projects. Besides just producing new buildings, it is important to also consider and transform the existing built environment.

> "*The process starts with transformation instead of new built as almost 99% of the real estate is existing, only 1% of it is new. So, we have a huge chance to circularly transform the existing built environment.*" — (Developer B, personal communication, April 8, 2021)

Some of the strategies being implemented from Developer A consider the introduction of building passports of the building to be handed to the owner once the project is completed. These building passports should hold information on the type of materials and products that the building obtains. Implementing such strategy is expected to increase the value of the building as precise information will be available during the transformation or renovation moments in the reverse loops. In addition, Developer A is aligning their process operations towards the use of bio-based materials and developing building components as a service. On the other hand, Developer B mainly tackles the existing built environment through circular strategies, such as deconstruction of the building components or circular purchasing of reusable materials from external projects.

> "*We start by analysing all the layers of the purchased buildings, and per layer it is estimated what materials and components are good that can stay and what's not good and has to be removed. The removed components are attempted to be re-manufactured and used again in the building itself. If that's not possible, potential reuse in other projects is evaluated or it is recycled. In addition, we also purchase in a circular manner from other projects or reuse materials.*" — (Developer B, personal communication, April 8, 2021)

Table 6-3: Overview of case findings (Project Developer)

Analysis Variables	Description per case	
	Developer A	*Developer B*
Production environment		
Operation and process coordination	Internalise operations and processes, such as the concept development and design.	Internalise not only developing and design processes, but also investing operations for their projects. Processes rely on five main building principles: (i) preciousness, (ii) healthy, (iii) dynamic, (iv) circular and (v) interactive building.
Circular reverse loops	Stakeholders: Introduction of a reclamation expert. Information: Need of a material passport within which detailed technical information is available to all stakeholders.	Stakeholders: When dealing with the transformation project of an existing building, a big team of structural engineers, architects, building service engineers, developers and managers are integrally collaborating between each other since the initiation phases. Information: Technical information of the building components and materials is crucial to be available to all stakeholders.
Strategy integration	A circular supply chain is expected to provide a steady financial income due to the building consisting of components leased as a service. Strategies: Introduction of building material passports, aligning their operation processes towards the use of bio-based materials and developing building components as a service.	A circular supply chain is enabled when addressing not only new-built projects but also transformation and renovation projects of the existing built environment. The main circular strategy aligns with the aim to extend the life-cycle of a building and its components by re-purposing routes. In addition, each existing building project is analysed to identify deconstruction possibilities.
Organisation environment		
Internal alignment	Area development is the core expertise, which together with their in-house disciplines (area marketing, concept development, area and planning economy, (sales) communication, finance and legal) are used to help shape an integrated development approach.	Focused in coordinating and influencing the development phases of the project towards a circular built environment by becoming their own client and investor.
Cross-chain collaboration	Active member of the LenteAkkoord organisation for the development of energy-neutral new-built, or participant in the city deal 'A smart city'; external collaboration that research and develop methodologies for practical implementation of a climate-adaptive construction.	Established partnerships when starting a transformation project that help operate the analysis, waste management and the overall transformation process of the building.
Information exchange	Considers information exchange as very important. Barriers of information exchange: from manufacturers as it does not provide benefits to the business and it creates additional costs. Information system: No integrated information system identified; mainly use of SharePoint system internally and externally through some filters.	Considers information exchange as very important. Barriers in information exchange: due to lack of proper technical information in archives for the existing buildings. Information system: Use of BIM.
Control environment		
ICT architecture requirements & functionalities	Quick connect capability to other ICTs that allow for data exchange; Material properties data exchange	Align stakeholders of a supply chain with each other. (Event Management); Include the legal line properties, such as permits or contracts and the financial aspects of the processes.
Control facilitators across supply chains	New independent facilitator.	Project developers or project managers as they oversee the whole process.
Circular building tools	Use of Madaster for creating material passports and assisting MPG calculations.	Madaster, and own team to laser and analysing the transformation building projects.
Social environment		
Legal, financial & cultural factors	Legal: No legal context evidence identified. Financial: No financial context evidence identified. Cultural: Differences between the types of clients and types of projects. Main difference observed in residential projects as private clients are less willing to incorporate circular principles into the project.	Legal: Insufficient regulatory context supporting a circular built environment. Financial: Distinctive difference between a new-built and transformation project. Finances are higher for a transformation project due to higher uncertainties. Cultural: There is no a high interest from developer or investors into circular projects.

6-4-2 Organisation environment

Internal alignment

Area development is the core expertise of Developer A, which together with their in-house disciplines (area marketing, concept development, area and planning economy, (sales) communication, finance and legal) are used to help shape an integrated development approach. Developer A works with various parties on innovative solutions for areas and buildings from initiation to delivery to its users. Sustainability and circular developments are core values in the working method. These values are achieved by following their four pillars: energy transition, circular development, climate adaptation and sustainable mobility. Objectives have been formulated for each pillar that the new projects must meet and reviewed annually.

The approach of Developer B to the building supply chain environment is focused in coordinating and influencing the development phases of the project, specifically in healthcare and education. Currently, the internal alignment has shifted towards being their own client and investor in order to make sure their five principles (preciousness, health, dynamic, circular and interactive building) are met. First, *preciousness* is understood as the feeling attached to the building. Second, a *healthy building* means that it has been built in a conscious manner by taking into account the physical and mental health of its users. Third, a dynamic building, this is aligned to flexibility to change its function based on demand changes. Next, circular building, which is understood as the ability to (de-) construct and reuse the materials and products within a building. Lastly, an *interactive building* stimulates through its layout and design interaction between its users.

> "*We started as project managers and during this time we had to convince all kinds of parties and that was really hard and energy draining. Therefore, six years ago, we made a choice to start developing ourselves. However, we noticed barriers when developing circular buildings. Although we add a lot of quality in the building by doing so, investors are not willing to pay for it. Thus, we have become also an investor ourselves. It is not necessary for us to develop 1000 projects. We need to make impact by a few projects per year where people talk about.*" — Developer B, personal communication, April 8, 2021)

Cross-chain collaboration

In order to deliver a successful building, the developers arrange collaborations with external stakeholders, such as architects, contractors and other firms. In addition, to propagate their sustainable and circular objectives these external collaborations are necessary. The collaborations may be temporary or long-term encompassing different projects. For example, Developer B has partners when starting a transformation project that help them operate the analysis, waste management and the overall transformation process of the building. An example of such partnership is with Demolishing Company A helping in the harvesting of used materials or ClicBrics as an innovative producer for buildings.

Developer A is also active outside of its own organisations, by being an active member of the Lente Akkoord organisation for the development of energy-neutral new-built, or participant in the city deal 'A smart city'. These is a different type of external collaboration from the previous developer, which researches and develops methodologies for practical implementation of climate-adaptive construction.

> "*The present model is that developers make a concept design, and when the design is finalised up to a certain level, we bring in other stakeholders, such as construction companies to join the team.*" — (Developer A, personal communication, April 28, 2021)

Information exchange

The interviewed organisations hold different types of information, stored into different information systems. A general overview of these systems was provided in Section **??**. Through the interviews it was noticed that both stakeholders found information exchange between stakeholders as highly important in order to enable a circular supply chain. However, barriers were noticed in the willingness to exchange information between different stakeholders. For instance, Developer A argues that manufacturers do not provide a detailed information on the product and material properties of the building components, unless they asked to. This barrier is enhanced when dealing with a transformation project as the overtime changes are also not been mapped. Developer B gives an example of such a situation, where the reported measurements of the floors did not correspond to the real situation and this resulted extra costs as the materials had to be reordered. Developer A suggests that in case the detailed technical information is not possible to be shared then a KPI system providing information on the performance of the product or material could be sufficient to enable the re-purposing in another location or building function. In addition, the information exchange is coordinated by the developer in a rather traditional way. It was mapped that Share Point is a platform being used to share information internally and externally. However, externally the information exchange is filtered as for example financial details are not shared. The developer is the stakeholder managing and controlling the major information flows.

> "*As a developer, I think it is crucial to exchange information, because we this information too. However, not all parties are used to share information, such as manufacturers do not provide a detailed list of all the materials used into the products as it costs money or does not deliver value to them. I think this will get resolved in the upcoming years as MPG and MFA calculations will become more important.*" — (Developer A, personal communication, April 28, 2021)

> "*From a technical point of view you encounter barriers in information as the archive information is not complete or the building has changed through time and the drawings don't show this.*" — (Developer B, personal communication, April 8, 2021)

6-4-3 Control environment

ICT architecture requirements & functionalities

During the interviews the developers were asked about the type of requirements and functionalities that are crucial for a control environment to facilitate a circular supply chain. Both developers provided new requirements in regards to the operations of a control centre, some similarly to what was identified in the literature section. Developer A mentioned the difficulties of sharing information because of current ICT systems are not compatible. Therefore, a control environment should allow for quick connectivity through a middle-ware software to other construction information systems like BIM, that allow for relevant data exchange.

> "*The digital information does not always match as the different systems do not connect or have a smooth translation of the information.*" — (Developer A, personal communication, April 28, 2021)

Developer B suggests that the legal and financial aspects need to also be added into the ICT architecture. For instance, an overview of the legal building permits and other juridical regulations need to be followed in the processes for a specific building project. Within this the financial aspects should also be transparent between the stakeholders within a supply chain. In regards to functionalities, detailed material properties seem to be extremely important. These properties should be open and accessible to all stakeholders in the supply chain as it allows them to guarantee their re-purposing possibilities in other supply chains.

"*Besides the regular construction processes and stakeholder management moments, there is also a juridical phase. If you buy a plot you need information on the regulations and zoning plans. In addition you also need to align the stakeholders of the supply chain and the financial lines of the process.*" — (Developer B, personal communication, April 8, 2021)

Control facilitator across supply chains

During the interviews developers also gave their perceptions on the entity acting as a facilitator of the control environment. The interviewed developers mentioned two different facilitators for a control centre. Developer B argues that either the developer or project management offices could be a facilitator as they oversee the entire project. However, a disadvantage of project manager offices is that they lack expertise in managing the financial factors of projects. Whilst, Developer A suggests that 'a new intermediate party' should be developed, thus a non existing stakeholder.

"*There will be a new intermediate party to potentially coordinate the routing of the materials to new destinations.*" — (Developer A, personal communication, April 28, 2021)

"*Maybe project developers can facilitate the control centre as we are the central information gathering or project management offices as they almost do the same as a developer. However, project management offices do not manage the financial lines very well as they only deal with the building costs. Thus, they will need the help of the developer.*" — (Developer B, personal communication, April 8, 2021)

Circular building tools integration

When asked about circular building tools, both developers stated that they did not fully make use of them. Madaster was the only tool that was mentioned and used internally by the organisations as it assisted their calculations for Milieu Prestatie Gebouwen (MPG). According to Developer B, these tools are not as applicable when undertaking renovation and transformation projects, as there is information lacking on what the building holds. Thus, for such buildings one needs to analyse the building manually. Furthermore, Developer A mentions that the design process is mainly tested on a manual basis as the calculations cannot be accurate due the 3D model lacking all the material components.

"*We do not use specific circular tools. We use Madaster and conduct MPG calculations. In addition, we also use BIM to add all the information since the beginning of the project, but we cannot make accurate calculations, because in BIM you only can add materials that are visible in the 3D model.*" — (Developer A, personal communication, April 28, 2021)

"*We do everything in BIM as we 10 years ago and as we still do. Also, we make material passports in them by working together with Madaster. But, in general we start analysing the building by confronting the drawings from archives with the current situation. This is done by our specialists through eye-checking. So we don't really have a tool for this.*" — (Developer B, personal communication, April 8, 2021)

6-4-4 Social environment

Legal, financial and cultural factors

The developer aims to add its principles and objectives within all undertaken projects. However, this cultural alignment is mainly applied internally in the organisation rather than externally with other supply chain partners. Developer A notices a big distinction between this cultural alignment on the type of projects that are undertaken.

> "*If we are talking about housing projects, it depends on the types of clients. If we have a private client, then circularity is not well-known or do not see the value as they do not benefit from it themselves. For energy-neutral and efficiency that was a clear advantage for the private owner as they spend less energy and money. However, similar benefits are not present for circularity at the moment. Whereas when we have a client that is an investor they request a circular building, as they see non-circular buildings as future stranded assets. From an investor point of view, circularity will become more important overtime, and some of them have noticed this and act on it.*" — (Developer A, personal communication, April 28, 2021)

Furthermore, Developer B addresses the financial dimension too for developing a circular supply chain. There is a significant difference on the financial line between a new-built and transformation project. A transformation project is more expensive then new-built as there are higher uncertainties from a technical and legal perspective. Technically, the existing built environment often lacks relevant information on the components held by the building or whether any renovations or changes happened during its operation time. This lack of information could increase costs when the not visible layers of the building are exposed, such as tilted floor structures or different measurements then anticipated. In addition, from a legal point of view currently transformations to a different function than its current one may be faced with banks not investing into the project as it does not correspond to the original function. AM strengthens the legal difficulties by stating that there is insufficient regulations that support circular principles.

> "*Transformations costs more than new built projects as parties do not finance a certain type of building. For instance, banks finance office buildings. We bought an old office building and planned to transform it into a (short-stay) hotel. However, due to this change in function the bank would not finance the project as they only do office buildings.*" — (Developer B, personal communication, April 8, 2021)

6-5 MCSCM Environment Perception | Project Manager

Project managers are another stakeholder with an important role in building project processes, as they oversee the entire process and enable the collaboration between the different stakeholders. Their influence towards the decision-making moments is significant, as their main responsibility lies into the organisation of the project team. Table 6-4 gives an overview of the findings.

Project Manager A works for an independent organisation that through its project and program managers take a leading role in the transition of a future-proof built environment. The main aim is to enable and support the collaboration between the private and public parties by supporting and promoting the application of innovative solutions in areas such as circularity, climate-adaptive or CO_2 neutral buildings.

Project Manager B is also from an organisation that focuses in developing a sustainable city development. The organisation contributes to sustainable cities by connecting the supply and demand for knowledge and innovations. Through their project managers, they are able to strengthen the knowledge position and innovative power of knowledge institutions, companies, governments and social organisations. Simultaneously act as a knowledge centre for sustainable innovation on a regional, national and international level.

6-5-1 Production environment

Operation and process coordination

The operation and process coordination of both project managers oversee tasks, such as interpretation of plans and specifications, the management of the design and construction processes, preparing program and cost estimates that meet the client's requirements and methods to meet the time, costs and quality requirements by the client. Their operation encompasses the entire process from initiation to complex design and construction interfaces to the handover periods and the interim payments. Both mangers bring forward circular principles into the processes of construction projects, for instance Project Manager B supporting transformation projects and aligning the other stakeholders towards the reuse of materials present in the existing building.

> "*We tend to use materials with as low environmental impact and costs. In addition, we also are trying to reuse as much of the existing materials, which could either be within the building or other used materials, but also leftovers from production, which normally are being thrown away. In the example project we didn't fully close the circle, but we mostly acted on the material aspect in the design and construction phases by minimising the amount of raw materials.*" — (Project Manager B, personal communication, April 23, 2021)

Circular reverse loops

In order to facilitate the creation of a return loop, Project Manager A suggests the process to start since the design phase. In this phase, project integration is crucial, in which the designers and contractors design suitable for disassembly of the building components. Design for disassembly is thought to extend and retain materials and products in different life-cycles. In addition, the use of more bio-based materials is another contribution to a reverse loop dimension. Crucial stakeholders for the establishment of reverse loops are thought to be asset managers and building owners, as they will retain the information needed of buildings.

> "*The first steps towards a circular economy would be to design for disassembly and that is the main thing for me that comes to mind. Next step would be in the same phase to choose and use more bio-based materials.*" — (Project Manager A, personal communication, April 22, 2021)

Project Manager B, adds that in order to create such loops, original manufacturers and suppliers need to be held accountable. However, this could be difficult due to the 'time' element in building projects, as there is no guarantee whether the accountable company will still exist when the life-cycle of a building ends. Therefore, there needs to be some type of information system that transfer the correct information to the proper third party stakeholders.

> "*In theory, you would prefer to have the original producers accountable for the operation and also maybe recovery of their building components. However, in reality, if you look at the lifetime of a building then it is not guaranteed that the same producer will still exist.*" — (Project Manager B, personal communication, April 23, 2021)

Strategy integration

Project Manager A emphasises that before we focus in the details on how to facilitate a circular supply chain, the big overview of the whole process needs to be identified. Thus, not just address the details of materials, but set up the steps starting from the design phase to the delivery and eventually recovery of the building. In addition, Project Manager A highlights the importance of transparency and information sharing as a crucial component in the establishment of a circular economy.

> "*To me a circular supply chain starts with the correct information, which is also the most troublesome part in these days for making a circular economy and the circular supply chain really take off. Currently, there is a lot of discussions about how to measure circularity or how to determine if something is circular or not and it still is unclear.*" — (Project Manager A, personal communication, April 22, 2021)

Project Manager B believes that there is more attention being given to the types of materials being used and their impact. In addition, besides the materials it is beneficial to have the right set of tools that facilitate a circular supply chain. According to Project Manager B, the current environment does not hold all the needed criteria to deliver a circular supply chain, but this should not be a barrier to still implement small circular aspects into the project, such as designing in a more conscious way or choosing less untactful materials.

> "*It is very important to accept that circularity is difficult and that at the moment it is difficult to realise a fully circular project.*" — (Project Manager B, personal communication, April 23, 2021)

6-5-2 Organisation environment

Internal alignment

The internal alignment of both project managers is towards the creation and facilitation of a circular and sustainable built environment, either on a building or urban level. The concept of circularity and implementation possibilities are the main focus of both organisations. Project manger A also provides that their internal alignment addresses six roles for addressing their goals (stimulate, communicate, connect, inspire, educate and measure). First, stimulating a sustainable built environment through sharing their knowledge and initiating research. This is communicated within projects and in independent reports over the best practices and projects. Besides the regular managerial tasks within projects of connecting different stakeholders, meetings and courses are organised to inspire and educate other organisations on current topics. Lastly, the internal alignment has opted for a set of tools that can help make the topic of circularly measurable and act as a common language internally and with their partners.

Cross-chain Collaboration

Besides the traditional collaborations within the supply chain stakeholders within a construction project, both organisations of the project managers have established external collaborations with a set of partners. These partners are either front-runners and attempting to aligning their internal business models towards circularity and sustainable environment. From these collaborations the knowledge is shared and new approaches are researched or developed.

Information Exchange

Project Manager A has observed that stakeholders are becoming more willing to share information with other stakeholders, as they see building in a circular way is getting an increased attention. In that regard, different stakeholders including Project Manager A are investigating how to adjust their processes and share necessary information in regard to circular construction projects. However, barriers in information sharing are still present, such as companies being sceptic in how much information should be shared, so that their advantage in the market is retained.

> "*A materials passport doesn't add any value to the materials that are in the in the building, because the information being stored is about the weight of steel or concrete in the building. What is important is for material passports to hold information on building components and how they can be constructed and deconstructed.*" — (Project Manager A, personal communication, April 22, 2021)

The information systems implemented in the organisation of Project Manager A are: BIM, overseeing the linear processes, and Madaster for the generation of material passports. An own information system is also developer for the same purpose as Madaster, to generate material passports. This is due to maintaining some clients requesting the information to be kept confidential, such as in the case of bank building project. No information systems were recorded in the interview with Project Manager B.

6-5-3 Control environment

ICT architecture requirements & functionalities

The element of time is seen as a crucial component in the functionality of a control centre, especially if it connects different project timelines and circular timelines. This will require for the standardisation of information and ability to exchange this information. In addition, as mentioned in the previous sections, there is a need to ensure a safe and secure system, which is accessible to a certain extent. Project Manager B adds to the functionality list the importance of data exchange ability between third party stakeholders, in case original manufacturers do not operate anymore.

Control facilitators across supply chains

Project Manager A suggests that control centre should not be facilitated by a commercial party as this may create a competitive market and issues in regards to privacy and safety of the information shared. Therefore, an independent entity is suggested for the ability to facilitate the control centre. However, it is also observed that asset managers or building owners will also play a crucial role in the process specifically for the reverse loops, as they will hold the necessary information of buildings and update it in case any changes are made due to maintenance. Project Manager B, emphasises their importance too and even argue that maybe they are the potential facilitators of the control centre.

> "*If a commercial company takes that position, there will always be another commercial company who thinks they can do it better. Thus, I think in the end it will come down to asset managers and building owners to share the information they hold the an independent control centre entity, who will then enable the share of information with contractors or developers.*" — (Project Manager A, personal communication, April 22, 2021)

Circular building tools integration

Both project managers made use of different circular building tools internally and in their projects. For instance, Project Manager A, first made use of Building Circularity Index (BCI). However, this required extensive information, which was not sufficient for the company. The current used tools are, Madaster, BREEAM-NL, "Duurzaamheidsparagraaf voor taxaties", "INSIDE/INSIDE voor duurzaam interieur", and their own developed tools for scanning the building and guidelines for circular. However, it is observed that these tools quite extensive while a well-established process is lacking.

Project Manager B, identified the use of EcoInvent and the Nationale Milieudatabase, which enables the comparison between materials. The two databases are able to be connected together. In addition, the Idemat app, developed by TU Delft was also used to provide a quick environmental impact analysis. Project Manager B also mentions the use of BREEAM at first, but switching later on, due to not being able to have a good overview on how some small changes in the design could impact the overall building performance.

> "*Two years ago, we were also working with BREAM to assess the environmental impact of buildings. However, the tool was very complex to use, as you need to have information and include a lot of characteristics before getting an overview of the impact, and if you make a change in the design it is harder to overview what impact that has on the overall performance.*" — (Project Manager B, personal communication, April 23, 2021)

6-5-4 Social environment

Legal, financial and cultural factors

From a legal perspective there are no specific regulations indicating that a certain amount of reused materials need to be incorporated in building projects. Project Manager A underlines that most stakeholders are not eager to reuse old materials and products, due to not enough guarantee on their quality and performance and financial reasons. Financially, stakeholders believe that the re-purposing of the materials should be less expensive than new materials, as their are thought to keep their worth over-time. However, in reality in order to keep a high quality of the materials or products there need to be maintenance plans in place. Maintenance and retraction of material and potential re-manufacturing requirements add to the financial costs for creating a circular economy.

In regards to the cultural dimension, Project Manager A argues that the majority of construction companies are more reactive than proactive. This means that the contractors react to client demand for a circular building, in order to implement circular principles. Furthermore, depending on the contracts in place and the linear process, often stakeholders are not always integrated in the project phases. For example, sometimes this results in construction companies even if they may have a proactive mindset, often they are discouraged due to being obliged to comply with the designs provided by the architect. Therefore, Project Manager A, saw the importance of their role and the impact a project manager could make to the construction process. No specific argumentation were recorded in regards to the three dimensions by Project Manager B.

> "*I noticed that construction companies are very reactive towards the client demand, whether that be a circular building or a building that just meets all regulations (...) Often the vision of what they make is disrupted, because they have to comply to the plan and design of an architect.*" — (Project Manager A, personal communication, April 22, 2021)

Table 6-4: Overview of case findings (Project Manager)

Analysis Variables	**Description per case**	
	Manager A	*Manager B*
Production environment		
Operation and process coordination	Their operation encompasses the entire process from initiation to complex design and construction interfaces to the handover periods and the interim payments	Supports transformation projects and aligns the other stakeholders towards the reuse of materials present in the existing building.
Circular reverse loops	Design for disassembly and the use of bio-based materials are identified as two crucial components in the establishment of such loops. Stakeholders: Having a more integrated project process, where contractors and suppliers are involved since the design phases. Information: Asset managers and building owners are crucial parties that hold the needed information on the building.	Stakeholders: Original manufacturers and suppliers should be held accountable to produce and retrieve their products. Information: Need to have information on the material details and the original manufacturers and suppliers.
Strategy integration	There is a lot of discussion on material details, however there is a need to establish a full circular process first and the information sharing channels.	It is believed that the current environment does not hold all the needed criteria to deliver a circular supply chain, but this should not be a barrier to still implement small circular aspects into the project, such as designing in a more conscious way or choosing less untactful materials.
Organisation environment		
Internal alignment	Internal alignment addresses six goals (stimulate, communicate, connect, inspire, educate and measure) and want to take a leading role in the transition towards a future-proof built environment.	Have embraced the importance of developing a circular city and want to strengthen their innovation and knowledge position on the matter.
Cross-chain collaboration	Traditional collaborations within the project process; collaboration with a set of external partners.	Traditional collaborations within the project process; collaboration with a set of external partners to share and develop new approaches.
Information exchange	More willingness to share information between each other as the importance of circularity increases. Barriers of information exchange: Scepticism from stakeholders to loose advantage in the market and due to privacy and safety reasons. Information system: Integrated BIM including design and construction processes. BIM is also connected to Madaster and own system to generate material passports.	No information systems were recorded.
Control environment		
ICT architecture requirements & functionalities	A safe and secure system that is accessed publicly to a certain extent	Data exchange ability to other stakeholders.
Control facilitators across supply chains	An independent entity that receives the required information from asset managers and building owners.	Building owners as they hold the information of buildings.

Table 6-4 continued from previous page

Analysis Variables	Description per case	
	Manager A	*Manager B*
Circular building tools	The current used tools are, Madaster, BREEAM-NL, “Duurzaamheidsparagraaf voor taxaties", “INSIDE/INSIDE voor duurzaam interieur", and their own developed tools for scanning the building and guidelines for circular.	EcoInvent and the Nationale Milieudatabase, which enables the comparison between materials and collaboration between tools. In addition, the Idemat app, developed by TU Delft was also used to provide a quick environmental impact analysis.
Social environment		
Legal, financial & cultural factors	Legal: No specific regulations that request the use of certain amount of reused materials. Financial: Circular building is more expensive than building new, due to maintenance costs and other re-manufacturing needs once the materials are harvested. Cultural: Stakeholders are more reactive to client demand than proactive towards implementation of circular principles. In addition, the lack of project integration in the initiation phases results in little impact possible from the parties involved in the later phases.	No specific argumentation were recorded in regards to the three factors.

6-6 MCSCM Environment Perception | Designer

In this case the designer is part of a design team, part of an organisation that focuses in different implementation aspects of circularity within the building industry. The organisation consists of several action teams and in its essence is a collective collaboration between different stakeholders on different aspects of circular building. Within this collaboration, the stakeholders enter into discussions to establish working agreements between each other and other companies.

The interviewed representative is involved in the action team that focus in investigating and set up circular design guidelines that will contribute to entire circular building process. The designer is part of the design action team and is in constant collaboration with other designers, architects and contractors working on design principles and strategies for a circular design.

6-6-1 Production environment

Operation and process coordination

According to the Designer and its action team, the concept of circularity has put under pressure the processes of design and construction. The designer acknowledges the change of processes to meet the circular building requirements. According to the designer, depending on the strategies that are chosen the project processes are adjusted accordingly. For instance, if the strategy to design with secondary materials is chosen, the additional process are needed, such as the harvest of materials or products from the existing built environment and processes that verify and certify their quality performance.

Circular reverse loops

The Designer case state that to establish an entire circular supply chain, the design phase needs to integrate actors active before and after the design is made. Involvement of stakeholders from other building phases is considered important in the design phase so that the proper strategies and methodologies are incorporates in the design. In addition, circular reverse loops are understood as the most critical point of the whole circular development as it can initiate another circular development, thus redeeming the value of the building. To establish such loops, monitoring, measuring performances and sharing information is crucial, in order to estimate past successes and mistakes.

Strategy integration

The designer identifies that circular design strategies differ from regular circular strategies as the former influences the following phases in the process. The designer argues that not every building project is suitable for the direct reuse of secondary materials. The Designer identifies six strategies, as seen in the list below. Per strategy the process interventions are shortly described:

- Preventive designing: focuses on preventing the use of products and materials, by analysing possibilities and forgoing design options that require demolishing and use of raw materials.
- Designing for life cycle impact reduction: considered design approaches that result in the least environmental impact throughout the entire life cycle.
- Designing with recycled materials strategy: has to do with the reuse of construction products or construction parts/elements of the same function that are currently in existing buildings.
- Designing for future-proof: takes into account solutions that allow the design to be adaptable to future demand requirements.
- Designing with secondary materials: involves designing with materials that has been used before or come from residual flows of other product system.
- Designing with renewable raw materials: takes into account exclusively building materials from renewable sources.

A draft report is drawn-up where each of the strategies is further explained with examples, and acts as communication medium to align different designers/architects.

6-6-2 Organisation environment

Internal alignment

The internal alignment of this case is highly directed to the analysis and researching of circular design requirements, strategies and implementation possibilities. This is achieved by the involvement of various company representatives from practice, that deal with design. Collectively discussions, researches and working agreements are established for a circular design, which contributes to the whole organisation ambition of understanding and implementing circular building in practice.

Cross-chain collaboration

As previously mentioned the organisation is set up with the purpose to enhance collaboration between various stakeholders. In order to come to working agreements that will be widely accepted, a significant number of people are involved. These people come from different companies and organisations and are willingly collaborating together to come up to a set of guidelines and working agreements. By doing this, means that the working agreements will be easily accepted within the building projects they undertake.

> "*So the organisation is a kind of bottom up approach. Within the action team there are 80 people from different companies working together to write up these standards and agreements. That means that both architects, suppliers and contractors agree with it. However, this is just a part of the chain who is familiar with circular projects, there are still some actors that are not involved yet in circular projects, which could lead to resistance to apply these standards.*" — (Designer, personal communication, April 2, 2021)

Information sharing

Information sharing is considered as a critical element in the establishment of circular design and project. By sharing information creative manners on how adapt and circularly develop a building can be found. The designer also recognises a difference in information sharing between a small scale and large scale project. Accordingly, in a larger project stakeholders are more willing to invest in information technologies and sharing information due to the increased complexity. While, in small scale projects due to the complexity levels being lower often such investments are not seen as necessary. Lastly, sharing joint databases and BIM are considered as systems that facilitate information exchange internally and across company borders.

> "*So the organisation is a kind of bottom up approach. Within the action team there are 80 people from different companies working together to write up these standards and agreements. That means that both architects, suppliers and contractors agree with it. However, this is just a part of the chain who is familiar with circular projects, there are still some actors that are not involved yet in circular projects, which could lead to resistance to apply these standards.*" — (Designer, personal communication, April 2, 2021)

Table 6-5: Overview of case findings (Designer)

Analysis Variables	**Description per case**
	Designer
Production environment	
Operation and process coordination	The designer acknowledges the change of processes to meet the circular building requirements. These changes depend on the strategies that are chosen and the project processes are adjusted accordingly.
Circular reverse loops	The Designer is researching possibilities to enable such loops since the design phase. Stakeholders: The design phase needs to integrate actors active before and after the design is made, for addressing appropriate circular strategies for the project. Information: The monitoring, measuring performances and sharing information is crucial, in order to estimate past successes and mistakes.
Strategy integration	Within the designer team six design strategies have been identified: (i) preventive designing, (ii) designing for life cycle impact reduction, (iii) designing with recycled materials strategy, (iv) designing for future-proof, (v) designing with secondary materials, (vi) designing with renewable raw materials.
Organisation environment	
Internal alignment	The designer is actively part of an organisation that focuses in the research of how circularity can be integrated within the building industry. The designer is focused in the action team that investigates and reaches working agreements in regards to circular design. Collectively discussions, researches and working agreements are established for a circular design, which contributes to the whole organisation ambition of understanding and implementing circular building in practice.
Cross-chain collaboration	The action team the designer is part of, consists of a collaboration between around 60 people that come from various companies and are involved with designing tasks within the chain.

Table 6-5 continued from previous page

Analysis Variables	Description per case
	Designer
Information exchange	Information sharing is considered as a critical element in the establishment of circular design and project. Differences observed between large and small scale projects; for instance, in a larger project stakeholders are more willing to invest in information technologies and sharing information due to the increased complexity.
Control environment	
ICT architecture requirements & functionalities	Digitisation is considered to play an important role for the achievement of the circular ambition. Material passports for the new developed buildings and respective database is necessary; tools should provide an overview of the inventory of available materials and products; compare options to enable the most appropriate choice for the project at hand to be made.
Control facilitators across supply chains	No information was recorded in regards to the facilitators of the control environment.
Circular building tools	No information was recorded during the interviews on the type of circular building tools used.
Social environment	
Legal, financial & cultural factors	Legal: The Designer recognises that the government is active and has several ambitions towards a circular building industry. However, they are noticed to often contradict each other. Financial: parties operating in the financial markets, such as banks, insurance companies or pension funds, are becoming more interested in creating conditions and possibilities to finance circular projects differently. Cultural: It is observed that these guidelines may not be accepted by other companies and representatives who were not involved in the process.

6-6-3 Control environment

ICT architecture requirements & functionalities

Digitisation is considered to play an important role for the achievement of the circular ambition. By having a clear understanding of the inventory of the buildings, public space and greenery, it enables an overview of what can be (re-) used from the designer during the design phase. Therefore, material passports for the new developed buildings and respective database is necessary to provide insight into the current stock. In addition, it is reviewed that collaboration is necessary between the different circular building tools and platforms currently in the market. The tools within the circular control environment should provide an overview of the inventory of available materials and products for designers to design with these in mind. Next, tools should have the functionality to compare options to enable designers and other stakeholders to make the most appropriate choice for the project at hand. Lastly, it was recorded that the control environment should continuously monitor the total circularity performance of the design and construction works in a supply chain or industry.

Control facilitators across supply chains

No information was recorded in regards to the facilitators of the control environment.

Circular building tools

No information was recorded during the interviews on the type of circular building tools used.

6-6-4 Social environment

Legal, financial and cultural factors

The Designer's action team has also identified several barriers in regards to the three social environment factors. In regards to, the legal and regulatory perspective, the ecosystem that the government facilitates is considered to either accelerate or slow-down the transition to a circular economy. The Designer recognises that the government is active and has several ambitions towards a circular building industry. However, they are noticed to often contradict each other. Therefore, to achieve particularly a circular design the Designer identifies that effort needs to be put in both public and private law regulations that support circular building design principles, such as the use of secondary materials instead of being declared as waste.

The designer team also recognise that parties operating in the financial markets, such as banks, insurance companies or pension funds, are becoming more interested in creating conditions and possibilities to finance circular projects differently. Within different banks new circular financial arrangements can be found wither for the building or product/material level. In addition, Designer argues that the feasibility of the design depends on choices that are made in the initiation phases and the budget. Overall, the finances of a circular design are translated into higher final value of resource usage, and monetary value. According to the Designer case, circular design and building requires different financial possibilities, whereby considerations of the residual value of materials and incorporating CO_2 impact in the credit applications are central.

In regards to the cultural perspective, although a large number of people is involved in the action team to come up with a set of guidelines regarding circular design and construction it is observed that these guidelines may not be accepted by other companies and representatives who were not involved in the process. The traditional way of working is still highly visible in the market, which comes from a lack of urgency to transition towards circular building.

6-7 MCSCM Environment Perception | Contractor

Contractors are considered as primary stakeholders but on a lower level than developers and municipalities. They still have direct influence on the construction project phases (Chinyio & Olomolaiye, 2009). Usually, the main activities revolve the production of construction plans and specifications on the planning of all construction processes. In this case two different contracting companies were interviewed.

Contractor A is a well-established company, operating nationally in the Netherlands. Their core activities concern the development and realisation of construction and infrastructure projects, together with their maintenance or renovation. These activities are founded on a solid financial basis and an open and reliable business style.

Contractor B is a company that combines activities between the areas of real estate, construction, technology and infrastructure. However, a special focus is put in the development of residential areas. Quality improvements, innovation and integration of a healthy living environment are main aspects that these contractor aims to deliver to their clients.

6-7-1 Production environment

Operation and process coordination

The business and production processes of Contractor A are integrated in-house based on partnerships with several sub-contractors and suppliers. The processes are coordinated centrally through an open-source approach. The partnerships however are considered as external business units and are only notified by the approach based on the planning, but detailed internal information is not shared. In addition, the circular construction hub is another process that is mainly being coordinated internally. This hub works as a (temporary) storage for product and materials harvested by a project undertaken by the company. As the company operates nationally in the Netherlands, the projects are located in different parts of the country, and sometimes the stored products are re-purposed in other projects undertaken by Contractor A.

> "*The circular construction hub has only been online for a month and we already see a lot of demand from our in-house partners asking to re-purpose some of the products in their projects*" — (Contractor A, personal communication, April 13, 2021)

Besides the construction processes, such as supplying and manufacturing building components and their transportation to the site, Contractor B is also able to provide the design and maintenance of the building. In addition, the majority of materials used in their projects are mainly purchased by third-party suppliers. These purchased materials are new ones specifically for the residential and office construction projects. The infrastructure department is currently experimenting with the re-purposing of used materials. Due to the involvement in multiple building phases, such as designing, construction and maintenance, Contractor B sees the value of change their processes towards circular building.

> "*Besides the construction phases we also design and maintain the buildings. In that case we can participate in all of the moments in the process, which makes building in a circular way interesting.*" — (Contractor B, personal communication, April 13, 2021)

Circular reverse loops

In order to enable return loops several requirements were identified by both contractors. First, the technical information of the building components is considered crucial for the estimation of product's harvesting potential. Contractor A also addresses the importance of the 'time' element. The creation of only closed-reverse loops is not sufficient to create a circular circulation of the materials. According to Contractor A there is a need to establish relationships with different construction companies in order to initiate a fast-movement of the harvested materials, which would result in less storage time of the materials and would enable an instant circular loop. When addressing the organisational structure of these reverse loops, both contractors mentioned the importance of demolishing companies in the process as they have influence in the time schedules on when materials/products are taken out of the building. In addition, Contractor B addresses the role of the building owners as they will have a significant influence on the decision-making of the building during the operational phase.

> "*Timing is critical and knowing when a building is deconstructed, and of course the drawings where details are stored of these building components*" — (Contractor A, personal communication, April 13, 2021)

> "*We make the drawings, construct it and deliver it to its owner. What happens within the 20 to 40 years of using the buildings, we do not know. Therefore, the building owner should take action after those years.*" — (Contractor B, personal communication, April 13, 2021)

Strategy integration

The contractors in this case were both interested in the concept of circularity and recognise the increasing importance of implementing corresponding strategies. The circular construction hub is one of the strategies being implemented by Contractor A. However, this is currently being mainly implemented internally. The harvesting of the building materials/products, which is currently done by the demolishing companies is another activity that Contractor A wants to integrate into the internal processes of the company. Both contractors identified the need to implement circular design strategies, such as designing for disassembly, where the building is made of components that act as a service.

> "*The perfect scenario would be by starting to design for disassembly. The reuse of building elements is much better for the environment than some downgraded materials (...) We would prefer to reuse complete facades rather than aluminium window frames, glass and so forth. We want to buy the whole window and design it in.*" — (Contractor A, personal communication, April 13, 2021)

6-7-2 Organisation environment

Internal alignment

The ambitions of Contractor A encompass sustainability, safeguarding quality, digitisation and modern employment relationships. Innovation is an important element in the organisations and is continuously stimulated and coordinated within the organisation. The topic of circularity has gained attention in the company and internal implementation possibilities are being investigate. The undertaken building projects, test and support innovative construction methods since the initial phases of the project. In addition to the interim storage of new building materials, used building materials and building elements and parts can also be temporarily stored, processed and given a new purpose there. This is where storage and transport from the region come together.

The internal alignment of Contractor B, is focused on three main principles: (i) improving, (ii) smarten up and (iii) sustainability. The improving principle encompasses the internal processes and the ability to actively focus on risk and contract management, whilst attempting to improve. Next, the smarten up principle focuses on the introduction of technologies and innovations that support the internal processes of Contractor B. For instance, the creation of a digital twin of building projects, as it enables monitoring and better control over the project. Lastly, the sustainability principle addresses the designing processes, decentralising energy production and the efficient (re) use of the resources. They aim to standardise products, including here the concept homes, and opting for more conscious choices of materials. This is expected to enable the reuse of materials/products and the ability to renovate instead of building new. In addition, choosing logistics solutions that prevent unnecessary transport movements are also an important element that the contractor exert their influence upon the chain.

> "*The ambitions are high in 2020. We want to be at the forefront of quality, sustainability, digitisation and modern employment relationships. Some high-profile topics in which we invest are generative design, the application of bio-based materials and the 'circular road'. By taking our responsibility, we add lasting value to a sustainable living environment for everyone.*" — (Contractor A, personal communication, April 13, 2021)

Cross-chain collaboration

The current collaboration seems to still follow the traditional methods. These collaborations could be either temporary or long-term with partners that the contractors have worked with in the past. There are agreements and contracts with a number of sub-contractors and suppliers. In regards to external collaboration specifically for circular projects, Contractor A argues that little collaboration is being achieved. This often comes, due to not many companies having an internal alignment and processes that support circular principles. However, some long-term collaborations are being made with suppliers that provide wooden construction, as this is seen as a sustainable way of construction.

Contractor B has integrated the entire process and the supply chain, including a number of partners and suppliers, with whom long-term relationships have been established. They see collaboration as an important element for valuable ideas to arise. They aim to lead their construction chain and collaborations by continuously improving and taking full advantage of opportunities for process standardisation.

> "*Since in the early stages of a project we tend to discuss and lead the collaborations with them. However, we also see for example how wooden constructions are becoming more important, so we make deals for the next two years, or we consider purchasing a factory to produce ourselves.*" — (Contractor A, personal communication, April 13, 2021)

> "*For example, we collaborate with Madaster, who helps put our buildings in a database. However, collaborations with circular front-runners is not common, because the clients do not ask for a circular building. Most clients are not willing to pay when they are seeing what all the circularity costs are. Thus, it must really be something that our company initiates.*" — (Contractor A, personal communication, April 13, 2021)

Table 6-6: Overview of case findings (Contractor)

Analysis Variables	Description per case	
	Contractor A	*Contractor B*
Production environment		
Operation and process coordination	The businesses and production processes are integrated in-house based on partnerships with several sub-contractors and suppliers. The processes are coordinated centrally through an open-source approach.	Besides the construction processes, such as supplying and manufacturing building components and their transportation to the site, also able to provide the design and maintenance of the building.
Circular reverse loops	Stakeholders: Identify the importance of demolishing companies and established relationships with different construction companies to enable fast-movement of materials. Process: Important to have technical details over the building materials and products.	Stakeholders: Identify the importance of building owners to initiate the process and provide the needed information. Process: Important to have technical details over the building materials and products.
Strategy integration	Circular supply chain is seen to have its start since the design phase (design for disassembly). Special focus on the circulation of materials and internal establishment of a circular hub.	A circular supply chain is enabled when addressing not only new-built projects but also transformation and renovation projects of the existing built environment. The main circular strategy aligns with the aim to extend the life-cycle of a building and its components by re-purposing routes. In addition, each existing building project is analysed to identify deconstruction possibilities.
Organisation environment		
Internal alignment	The internal alignment goes beyond the traditional by addressing sustainability, safeguarding quality, digitisation and modern employment relationships.	Alignment focused in three main principles (i) improving, (ii) smarten up and (iii) sustainability.
Cross-chain collaboration	Collaboration follows the traditional methods lied down in contracts and agreements. Little collaboration on circular supply chain.	Circular supply chain is seen to have its start since the design phase (design for disassembly) and conscious choice of materials used.

Table 6-6 continued from previous page

Analysis Variables	Description per case	
	Contractor A	*Contractor B*
Information exchange	Oversee the exchange of information between the different stakeholders. Barriers of information exchange: Even based on partnerships, little willingness to share information on the delivered products in order to keep market advantage. Difficulties with updating changes and delivering materials in time. Information system: Use of KYP, BIM, GIS and own system holding information on the construction planning and order. All systems are connected to BIM.	Oversee the exchange of information between the different stakeholders. Barriers of information exchange: Lack of transparency over product and material details from stakeholders. Information system: Only BIM was identified.
Control environment		
ICT architecture requirements & functionalities	Provide timely and correct information; Data exchange with filtering possibilities.	Open for all supply chain organisations; coordinate cross-chain information flow; maximise logistical distribution of harvested materials.
Control facilitators across supply chains	Suggests that the contractor function could take this role, as they act as the focal point of communication between stakeholders.	An independent party to avoid the possibility of a specific stakeholder focusing only on their own projects.
Circular building tools	No specific circular building tools were identified.	Use of Madaster, which assists in the creation of material passports; BCI, MPG and LCA calculation techniques. Although they help during tender processes and for internal calculations, little coherence and no-connectivity possibilities were observed between the tools.
Social environment		
Legal, financial & cultural factors	Legal: There is no specific regulatory environment supporting circular processes. Financial: Important to keep their competitive advantage in the market. Thus, comply to client demand. Cultural: Main initiation towards circular building is taken by own initiative.	Legal: Legal environment is not sufficient when dealing with circular processes and government regulations are lacking. Financial: Important to keep their competitive advantage in the market. Thus comply to client demand. Cultural: Projects are highly influenced by client demand, who have little demand over circular building.

Information exchange

As main contractor companies, the contractors oversee the exchange of information between the different stakeholders. The contractors emphasise the value and importance of exchanging information between the different stakeholders. However, the willingness is to share information depends per stakeholders. For instance, suppliers are not willing to share all the specifications of the products that they deliver. Most of the companies are very protective towards their data as they want to retain the competitive advantage in the market. However, Contractor B states that such specifications will be crucial for the reverse loops to happen, as based on that information as it guarantees the performance of the material or product. Contractor A adds the barrier of updating in time the ability to deliver the materials and products in time, whether this be in the linear or circular process.

> "*As main contractor we are in charge of an open-source planner, accessible by all subcontractors and manufacturers. They are able to view the planning for the following two years and receive notifications when changes haven been applied to the planning.*" — (Contractor A, personal communication, April 13, 2021)

Based on the interviews and documentation several information systems used by contractors were identified: KYP, BIM, GIS and own systems. KYP also known as 'Keep Your Promise' is an information systems that holds data on the construction planning and orders. Contractor A uses this system for each project, and the information is exchanged and accessible between all involved parties. In addition, an own open-source planning system is used that oversees all the projects undertaken by the company. All these systems are connected to the BIM model, allowing notifications to be send to partnered sub-contractors and suppliers to provide offers for some specific building elements.

6-7-3 Control environment

ICT architecture requirements & functionalities

The main functionalities recommended by the contractors revolved the ability for the information to be filtered, providing timely and correct information, open for all supply chain organisations, coordinate information flow between different construction projects, manage logistical distribution of the harvested materials to storage places or other construction projects.

> "*I believe that setting some standards for everyone is important (...) how we deliver data, how the data is stored and connected to others.*" — (Contractor B, personal communication, April 13, 2021)

Control facilitators across supply chains

The contractors had different perceptions on who should act as a facilitator. Contractor A suggests that this ability should be placed on the contractors themselves, as they act as a focal organisation in the construction phase and have contact with other stakeholders throughout the supply chains, and therefore could facilitate a wider coordination. However, Contractor B, argues the importance of an independent entity facilitation a control centre, specifically for cross-chain collaboration, as it would evade the possibility of a specific stakeholder focusing only on their own projects.

> "*When you see the amount of data that is being stored by the government, I think that they have an important position in the control environment.*" — (Contractor B, personal communication, April 13, 2021)

Circular building tools integration

Contractor B had more experience with some of the circular building tools, such as Madaster, GPR Gebouw, Building Circularity Index (BCI) and LCA calculation techniques. Although the tools are used to assist calculations, it was identified that the lack coherence, connectivity and do not cover the whole dimension of circularity that the contractor wants to measure. In addition, MPG calculations are once again mentioned as they are required by the government. Although the tools do not deliver all the needs of Contractor B, benefits are observed due to their use, specifically during the tendering processes. The use of these tools acted as evidence that Contractor B had more experience in circular matters than the other contestants.

> "*It's to soon to say what the benefits are from circular tools ... maybe we won one or two more tenders, just by describing how we work and what tools we use.*" — (Contractor A, personal communication, April 13, 2021)

> "*When we enter tendering procedures we compete with other parties. In these moments we have seen that the use of circularity tools helps distinguish us from others and proves to the client that we have experience.*" — (Contractor B, personal communication, April 13, 2021)

6-7-4 Social environment

Legal, financial and cultural factors

A certain number of sub-contractors and suppliers are culturally close to the companies. According to Contractor B, suppliers are initiating the demand towards a more circular process. However, the cultural dimension of the clients seems to still be leaning towards the linear processes, and there is little demand towards circular projects. What is noticed from both contractors, is that the financial competitiveness remains important for the companies, and the lack of clients being willing to pay for circular implementation results in more traditional linear processes. In addition, the legal environment is also not sufficient when dealing with circular processes and government regulations are lacking.

> "*If we can't compete with other construction companies in Netherlands in regards to circular projects than we follow the linear processes. We can attempt to implement some circular strategies, but this would be our initiation as there are no specific governmental regulations to support such processes.*" — (Contractor A, personal communication, April 13, 2021)

> "*Often the clients have no demand for circular processes, which means that if we do implement circular strategies its purely from the company's initiation.*" — (Contractor B, personal communication, April 13, 2021)

6-8 MCSCM Environment Perception | Supplier

In this case, the supplier focuses into the development and provision of an integrated housing product; circular kitchens. The concept of circular kitchen was developed with the aim to address the large amount of waste that the linear process is producing specifically for kitchens. The standard process disposes kitchens being used in the built environment approximately after 15 years contributing to the increase of waste from the built environment. Therefore, the integrated circular product intends to become an example on how suppliers take responsibility over the products being made.

6-8-1 Production environment

Operation and process coordination

In order to deliver a circular kitchen component to different building projects the supplier is partnered with a fixed number of manufacturers working towards the same goal. The design process addresses the concept of 'design for disassembly'. In addition, the business model has been adjusted from selling these kitchens to leasing them for a fixed quarterly/monthly/yearly cost. In addition, due to being owners of the products, maintenance operation processes are also provided. Once the contracts end, the recovery process occur, where the main supplier takes back the kitchens and due to in-place agreements return the corresponding materials to their manufacturers. Currently, the supplier is supplying only the social and free rental market, as these markets have the highest level of standardisation, consequently higher level of circularity can be achieved.

"*We provide a kitchen in two ways. One through a full operational lease, in which kitchens are being leased for a quarterly/monthly/yearly fee. At the end of the contract we take back the kitchens disassemble them by either reusing all the parts that we can reuse directly or returning the parts that cannot be used directly to the original producers. We have agreement with our producers for those parts. The other proposition is a buy-back guarantee in which our customers buy a kitchen with a contract that allows us to buy the kitchen back for a set residue value at the end of the contract. And on top of that, we also provide installation services and maintenance.*" — (Supplier, personal communication, May 3, 2021)

Circular reverse loops

The supplier has already aligned their business processes to enable the establishment of reverse loops. As previously discussed, the supplier provides their circular kitchens in two ways to the client, through a full-operational lease and buy-back agreement. Both options include the recovery of the kitchen service and the return of its components to the original manufacturers and producers. Agreements between the lead supplier and their chain partners has been established for the recovered kitchens to be returned to them for re-purposing reasons. However, as the built environment still operates in a linear way, the supplier suggests the importance to introduce a circularity salvage dealer or reclamation/dismantling expert that ensures the products that can be re-purposed are recovered and redistributed to original or third-party manufacturers.

"*We have made clear agreements with our chain partners regarding refurbishment, re-manufacturing and recycling possibilities for the returned products. This allows us to select materials with a durable character and a long service life allowing the kitchens to remain in a circular cycle*" — (Supplier, personal communication, May 3, 2021)

Strategy integration

Within the supplier team circular economy is understood as the reduction of raw material usage and the reuse of products and equipment. When discussing in detail about the concept of a circular supply chain, the supplier emphasised the importance of establishing a responsibility line between the suppliers or manufacturers and their products. Currently, products are being returned to diverse manufacturers, which results in the product being fully taken apart due to little information on the product. Therefore, by creating a take-back system to the original producers it is thought to create a more conscious and responsible process of production as they will have to take back the product. This will influence the production process and also the quality of the product.

"*A circular supply chain first and foremost is a supply chain in which all actors take responsibility for what they produce. Every producer should take responsibility for how they produce a product and what type of materials they use. Eventually, for a circular supply chain, getting the responsibility for product back to the producer is key, because they will have all the details of the products and the knowledge how to deconstruct or reuse the product.* " — (Supplier, personal communication, May 3, 2021)

6-8-2 Organisation environment

Internal alignment

The supplier is mainly focused in developing products for the infill of a building. Currently, their main focus lies in the development of a circular kitchen as a service to different building projects. This is the suppliers way of reducing the pressure on the kitchen industry and supporting the transition towards circular economy system. The internal alignment of the supplier is fully focused in designing and delivering products that are easy to be deconstructed and taken back after their service-life is over. The aim here is to offer a competitive alternative to the traditional manufacturers and suppliers.

> "*Our aim is to have a complete circular economy, so we definitely want to expand to other products. However, at the moment we are focusing on kitchens. Our goal is to inspire other companies to do the same. Currently, the Dutch market produces about 200,000 kitchens per year. While we are producing 10,000 kitchens within five years, meaning there are 190,000 linear kitchens being made. Thus, we need to motivate and stimulate other market parties to join in our mission, because we can not do it alone.*" — (Supplier, personal communication, May 3, 2021)

Cross-chain collaboration

The supplier is in constant collaboration with a fixed number of other suppliers and manufacturers that provide the needed materials for the integrated circular kitchen service. The installation and recovery services are the main function of the lead supplier, but still collaborating with their partners, by bringing the recovered materials to the original manufacturers. In addition, the supplier is actively sharing their knowledge with other kitchen market parties acting as a raw material supplier. This is done with the intention to inspire and motivate other parties and ultimately accelerate change towards a circular built environment.

> "*We have a business model that also makes it mandatory for us to take responsibility for our products, because our products always come back to us. So we provide services on the kitchens that will extend their life-span, like design for disassembly and reassembly, material passports and agreements with our key partners to take back what they produced.*" — (Supplier, personal communication, May 3, 2021)

Information exchange

The lead supplier is the owner of the data and in charge of providing the material passports of the products delivered in the projects. Currently, an information system called Primafact is used by the supplier to gather all the information over the integrated product, such as materials used, parameters of the materials, original suppliers and the purchases or leases. The information is mainly shared internally at the moment, but there has been demand from contractors to share such information, and the lead supplier seems to be willing to share it. In addition, for the material passports, it is currently being researched on how to share this data with an ICT external party, who will provide the software to store this information. The information system has not been identified yet, but it is thought to hold the ability to locate the destination of the products and estimate the time when they will return.

In regards to information exchange with partners and other stakeholders there is seen a resistance in sharing information. For instance, appliance manufacturers are not fully transparent on all the materials and other details used within their appliances.

> "*Right now we own the data and make the material passports, but we have initiated the process of doing that with an external party. They will also hold the data through a software that we're going to implement internally too (...) There is resistance to share information. For example, the appliance manufacturers can be a little bit more protective on the information of what goes into their appliances, and how the appliances are produced. Thus, there is definitely some resistance from some party. However, we believe that transparency is key for for a circular economy and from our perspective, we would like to share all the data we have.*" — (Supplier, personal communication, May 3, 2021)

Table 6-7: Overview of case findings (Supplier)

Analysis Variables	Description per case *Supplier*
Production environment	
Operation and process coordination	The process operations are coordinated mainly by the lead supplier towards circular principles. Starting with the designing process addressing the concept of 'design for disassembly', to the products being leased or sold with a buy-back agreement, to the product being recovered and returned to their original manufacturers.
Circular reverse loops	The supplier has already aligned their business processes to enable the establishment of reverse loops. Stakeholders: Suggestion to introduce a circularity salvage dealer or reclamation/dismantling expert that ensures the products that can be re-purposed are recovered and redistributed to original or third-party manufacturers. Information: The lead suppliers is in charge of the information flows between their partners and other stakeholders.
Strategy integration	Within the supplier team circular economy is understood as the reduction of raw material usage and the reuse of products and equipment. When discussing in detail about the concept of a circular supply chain, the supplier emphasised the importance of establishing a responsibility line between the suppliers or manufacturers and their products.
Organisation environment	
Internal alignment	The supplier is mainly focused in developing products for the infill of a building. Currently, their main focus lies in the development of a circular kitchen as a service to different construction projects.
Cross-chain collaboration	The supplier is in constant collaboration with a fixed number of other suppliers and manufacturers that provide the materials needed to deliver the integrated circular kitchen service.
Information exchange	The lead supplier is the owner of the data and in charge of providing the material passport of the products delivered in projects. They are willing to share the information with other stakeholders, as they believe transparency is key to a circular economy. Barriers of information exchange: Resistance from other stakeholders, such as manufacturers to share a detailed report over their produced products. Information system: Primafact and a new system to be determined.
Control environment	
ICT architecture requirements & functionalities	Allow for data exchange, transportation of products and building components to appropriate stakeholders and hold material passports.
Control facilitators across supply chains	Governmental body or an independent party from the market is suggested as the most appropriate facilitator of a control centre.
Circular building tools	The tools used by the suppliers were: Product circularity index (within BCI); Circulytics and LCA calculations.
Social environment	
Legal, financial & cultural factors	Legal: The regulations that are currently in place do not in their entirety support the governmental ambitions to become circular by 2050. Financial: The legislations mainly support the production of non-circular products, as the taxes on them are cheaper than circular products. Cultural: The cultural mindset of the different stakeholders is still mainly towards linear processes.

6-8-3 Control environment

ICT architecture requirements & functionalities

According to the supplier a control centre acting as an integrated central information system should be open and transparent and allow for data exchange from one party to the other. Beside transportation of the products to the original or third party suppliers and manufacturers, it should also hold the material passports of the building components and products.

Control facilitators across supply chains

The supplier embraces the control centre as a potential solution towards a circular supply chain, as it can oversee the information flows and products/materials towards the correct parties. It was suggested that a control centre could be a combination between a cloud-based information system and an operating party, who ensures the building being deconstructed correctly and the products are logistically distributed to the appropriate stakeholders and locations. The operating party should correspond to a independent party, such as a governmental body that operates independent from the market.

Circular building tools integration

Within the supplier organisation several circular tools are used. The Product Circularity Index, within the Building Circularity Index (BCI) by Alba Concepts, used to determine a score on the products and their compliance with circular principles. Next, a Circulytics score by The Ellen McArthur Foundation is also used to provide a score on the processes of the organisation. Furthermore, LCA calculations are also used internally to map the overall impact that their products have. By using these tools the supplier has mainly seen internal benefits as they act as benchmarks to map the progress of their operational processes. However, it is observed that the tools still shortfall in comprehending circularity in its entirety.

> "*There are a lot of scores and there is no silver-lining tool to measure circularity. However, it is a start towards measuring circularity of a building. The tools we use, provide us value as they show us whether we are in the right direction. The only thing is, that it would be better if everyone used the same method, then we would get transparency.*" — (Supplier, personal communication, May 3, 2021)

6-8-4 Social environment

Legal, financial and cultural factors

The supplier identifies several barriers within all three factors. First, the regulations that are currently in place do not in their entirety support the governmental ambitions to become circular by 2050. Secondly, the legislations mainly support the production of non-circular products, as the taxes on them are cheaper than circular products. From a financial perspective, a value-added tax (VAT) has to be paid not only when delivering the products but also for its recovery. This often discourages the clients and building owners to purchase and return the circular products. In addition, the cultural mindset of the different stakeholders is still mainly towards linear processes. This is also noticed towards the lead supplier own partners. For instance, the current mindset of manufacturers is build upon producing their products in large quantities and selling them, instead of taking responsibility to take them back.

> "*A barrier is the lack of legislation and the way of thinking of stakeholders. (...) Raw materials need to be taxed higher than recycled or reused materials. Right now we noticed that we have to pay the VAT twice for a circular product. If we sell a kitchen the fee paid once and if we bring it back the customer has to pay VAT again, and there is no legislation returning this second payment.*" — (Supplier, personal communication, May 3, 2021)

6-9 MCSCM Environment Perception | Logistics Service Provider

The logistics service providers have a key role in the supply chain, as they control and enable the flows of materials from one location to the other. In addition, the logistical distributions require coordination and correct information in order to execute their processes. Although this stakeholder has no direct influence on the decision-making of a circular building, they have impact on progress of the building phases, specifically in the construction phases. In addition, they will play an important role in the return distribution of the collected building materials

The interviewed logistic service provider is an innovative company who is already experimenting with logistical control centres to optimise their streams of materials. The focal company is well-established and has experience with special transport, machine movements and assembly. The company was founded with the ambition to establish a partnership of construction logistics specialists.

It should be noted that the recording for this interview had significant technical issues, and proper quotes were not always able to be derived.

6-9-1 Production environment

Operations and process coordination

The operations and processes are coordinated based on three main aspects that aim to guide the constriction team from the tendering to the delivery moment, towards efficient logistical distribution streams within a project. First, the processes of the company are directed towards the analysing the specific logistics needed for a project and its supply chain. Then, agreements and plans are drawn up with the other stakeholders to align the coordination of the processes. Lastly, execution of the delivers are centrally coordinated and organised, where the most optimal routes are estimated based on their control tower.

Circular reverse loops

The logistic service provider are continuously investigating possibilities on how to create more optimal routing of planning of logistics for the waste streams. Additionally, they are involved also in project dealing with circular demolishing/dismantling, and agreements or plans are made for the logistical plans for these return streams.

> "*We analyse each project and see how can make less waste stream movements, for example by bundelling more waste elements from different project together. (...) We also are involved with circular demolishing, and are currently involved in different seminars to talk about how this can be done.*" — (Logistics service provider, personal communication, April 16, 2021)

Strategy integration

No strategy integration in regards to circularity were properly recorded.

6-9-2 Organisation environment

Internal alignment

The focal company is internally aligned in a way that allows to support information exchange about construction logistics between the different stakeholders. Simultaneously, through working agreements and contracts are drawn up, based on their inventory resources and reserving ticket systems in order for efficient solutions and plans to be arranged with suppliers and deliveries on site. Their internal control tower oversees the different agreements, plannings and potential disruptions in case of unforeseen developments.

Cross-chain collaboration

As aforementioned the focal company acts as an adviser and collaborate closely with other construction logistic specialists. Through a top-down approach, the logistic service provider brings parties together and coordinate plans and time schedules that are appropriate to achieve the desired results. A well defined collaboration is considered as a critical element in the establishment of efficient construction logistics. The focal company acts as a chain overviewer and helps establish the collaborations needed between developers, contractors and other stakeholders, with the main focus to optimise logistical distributions. In addition, established collaborations with other companies are made for researching and developing new strategies of an efficient and effective construction logistics.

Information exchange

To establish collaboration, information exchange is crucial for the logistics service provider. Insight is provided on the data of all participants of the supply chain they are involved in, for the purpose to have an updated and timely information. Traditional logistic information systems were mentioned, which gave an overview on the planning and other distribution moments that the company had to do.

> "*We make use of different systems, that assist us in risk assessments, reservation systems which hold different calendars about delivery times, agreements or meetings with other stakeholders.*" — (Logistics service provider, personal communication, April 16, 2021)

6-9-3 Control environment

ICT architecture requirements & functionalities

The requirements and functionalities that were identified from the logistics service provider encompassed the ability to create maximise logistical efficiency and allow for flexibility qua timing and planning. In addition, information exchange and transparency with the different logistics specialists was considered very important. This also aligns with the cross-chain collaboration and having information on what materials are released and their redistribution to other projects.

Table 6-8: Overview of case findings (Logistic service provider)

Analysis Variables	Description per case *Logistic service provider*
Production environment	
Operation and process coordination	The operations and processes are coordinated based on three main aspects that aim to guide the constriction team from the tendering to the delivery moment, towards efficient logistical distribution streams within a project. Coordination centrally through a control tower.
Circular reverse loops	The logistic service provider are continuously investigating possibilities on how to create more optimal routing of planning of logistics for the waste streams.
Strategy integration	No strategy integration in regards to circularity were properly recorded.
Organisation environment	
Internal alignment	The focal company is internally aligned in a way that allows to support information exchange about construction logistics between the different stakeholders.
Cross-chain collaboration	Through a top-down approach, the logistic service provider brings parties together and coordinate plans and time schedules that are appropriate to achieve the desired results.
Information exchange	Information sharing is considered as a critical element in the establishment of circular design and project. Differences observed between large and small scale projects; for instance, in a larger project stakeholders are more willing to invest in information technologies and sharing information due to the increased complexity.
Control environment	
ICT architecture requirements & functionalities	Requirements and functionalities encompassed the ability to create maximise logistical efficiency and allow for flexibility qua timing and planning. In addition, information exchange and transparency with the different logistics specialists was considered very important.
Control facilitators across supply chains	The logistics specialist as they guide the construction team in the efficiency drive of the total logistics surrounding a project. They ensure that the agreements made are enforced and navigates knowledgeably between the many stakeholders, and are in possession of a control tower.
Circular building tools	No information was recorded during the interviews on the type of circular building tools used.
Social environment	
Legal, financial & cultural factors	Legal: No specific legal information was mapped. Financial: Project budgets should include financial estimations on creating a control environment, or hiring a logistical specialist that could assists a more efficient distribution of materials within and cross chain. Cultural: It is observed that behavioural changes are needed in regards to information sharing and ways of working were materials are released and collected on site at least one week before collection and distribution plans.

Control facilitators across supply chains

The logistics specialist guides the construction team in the efficiency drive of the total logistics surrounding a project. They ensure that the agreements made are enforced and navigates knowledgeably between the many stakeholders. They are currently in possession of the control tower, operated by a specialist, and consider their role to be critical in the proper planning and progress of building supply chain and overall completion of the project.

Circular building tools integration

No information was recorded in specific circular building tools used by the logistic service provider.

6-9-4 Social environment

Legal, financial and cultural factors

In regards to the social factors the logistic service provider recognised the need of behavioural changes from stakeholders. Change of behaviours related on the fact that for a circular supply chain, the collection of materials in construction sites needs to be more efficient or earlier that what currently happens. In addition, behaviour changes need to happen in regards to information exchange and becoming more transparent. In addition, financial barriers were also discussed, such as the project budgets not including financial estimations on creating a control environment, or having a logistical specialist that could assists a more efficient distribution of materials within and cross chain. Legal factors were not addressed in the interview.

> "*Building reverse logistics is very simple to happen, but we need people to collaborate for the materials to be released and bundled at least one week before it needs to be delivered. No one is taking the initiative to do this, so we need to see how can we incentivise people to do this.*" — (Logistics service provider, personal communication, April 16, 2021)

6-10 MCSCM Environment Perception| Dismantler/Demolisher

In the traditional construction project this stakeholder is known as a demolishing company, involved once a building reaches its end of life. As mentioned in Section 4-3, some companies representing this stakeholder are adapting their processes towards circular principles. Thus, embracing the circular dismantler stakeholder position. This means that instead of demolishing, analysis and researches are done on deconstruction possibilities per building project.

Dismantler A is a front-runner in the demolishing sector that has transformed their operations and processes towards a more circular business model. Challenging the demolishing sector, they have not only become a dismantling company, but have expanded to also supplying building materials that contribute to a circular economic model. To this end they develop and produce materials in a conscious way by re-purposing or from bio based. The also research and develop new financial models, together with measurement tools and valuation systems.

Dismantler B similar to the previous company is a front0runner in the demolishing sector and is changing their processes from only demolishing to disassembly possibilities of buildings. The harvested materials are redistributed either to be reused or are placed for purchase possibilities through the company's own market place. Their aim is to have an environmental and societal impact due to their operations.

6-10-1 Production environment

Operation and process coordination

The operation and processes of Dismantler A are coordinated through two main collectives. First, the urban mining collective hold approximately twenty five partnerships, where each of the partner is a specialist in a specific building materials or component. To enable a wide application of the materials provided by Dismantler A, their internal coordination utilises existing order and distribution systems. Thus, once the building materials have been harvested they are sorted in an efficient way for their distribution to internal storage units. These materials are then purchased by these partners, who then are in charge of re-manufacturing or reuse them directly to other projects.

> "*We harvest the materials and then involve our partners, who also have their own projects. For example or partnered logistic service providers once they deliver materials to certain project they pick up our harvested materials on their way back, which are perfectly sorted and they only have to load them. These materials are transported to the storage units and from there it has a direct selling point because they have also integrated it on their website*" — (Dismantler A, personal communication, April 8, 2021)

The operation and process coordination of Dismantler B is dependent whether a new built or transformation project is undertaken. In the case of new built the company advises on the possibilities of reused and recycled materials to be implemented in the project. The process of transformation starts by first scanning the building to identify all materials present in the building, which then gives room for negotiation and consensuses to be reached with other stakeholders to make use of them in the new project. Then, the in-house deconstruction team disassemble as many materials and products which can either be reused directly or are transported to in-house circular storage hubs. These hubs act as storage and as workshop to re-manufacture some of the materials. These materials are places into a web-shop ready to be purchased by contractors and re-purposed in other projects. All these processes are coordinated internally.

> "*We tend to act quickly on site and actually refurbish offsite. Due to this, we are able to refurbish as many products as possible. What is very interesting is that the demolition of the building is the end of the cycle, but at the same plot the new cycle begins. Thus, we make material passports during that process and reach consensuses with developers and architects for their reuse in the new project.*" — (Dismantler B, personal communication, April 21, 2021)

Circular reverse loops

Dismantler A is already facilitating a reverse loop dimension, based on the information derived from their operation and process coordination and internal alignment. They currently, have established an overseeing role over the whole supply chain. Based on their observations in order to properly facilitate, the initiative process phases are crucial. It seen important to bring to the table not only the stakeholders with financial power, but also the stakeholders in the indirect environment, such as suppliers as they have more knowledge on their inventories and circular materials. Within the linear process, sub-contractors or suppliers are introduced later in the process and have little influence in the designs and project process as a whole. Dismantler B suggests also the introduction of a new stakeholders into the process, that of a 'performance certifier'. This stakeholder would evaluate the performance and ability to be re-purposed in new life-cycles of harvested materials. In addition, the logistic part of the whole process seems to be very important in order to make the circulation of materials swiftly and fast.

> "*When you are at the lower phases of working, like a sub-contractor they cannot make the change. Thus you have to make the change from top-down, but also integrate everyone and share knowledge about why it is important to use circular materials.*" — (Dismantler A, personal communication, April 8, 2021)

> "*If you have a third party who can validate this harvested product and therefore give a guarantee over how fire resistant it is or how much isolation value it has and so on. I think this would be a big added value to the circular economy.*" — (Dismantler B, personal communication, April 21, 2021)

Strategy integration

A circular supply chain is understood beyond just recycling. A CSC should be able to contain and add value to the materials circulating by re-purposing them in different life-cycles. Currently, the built environment is faced with several different definitions and perception on what a circular economy is. Although there is more attention being given to the concept and more companies are attempting to implement more circular strategies, one is still faced with the greenwashing problem, such as companies down-cycling materials rather than up-cycling. Dismantler A strategy integration concerns the deconstructing a building in components and materials that can either be directly reused or re-manufactured to be then re-purposed in other building projects.

Dismantler B strategies align with those of Dismantler A, their aim to disassemble instead of demolish , and directly reuse or re-purpose as many materials/products as possible. Interestingly, they see once the linear cycle becoming more circular, due to these strategies and change of mindset.

> "*What is interesting is that before the cycle would end with the demolition of the building and then on that same plot the new cycle would start. So with what we do, by making these material passports and discussing with developers, construction companies and architects to try integrate as many of these materials in the new design. So where you first saw a linear line, you now start seeing a circle.*" — (Dismantler B, personal communication, April 21, 2021)

6-10-2 Organisation environment

Internal alignment

Dismantler A is still new to the market, and at first their internal alignment was mainly focused in the harvesting of buildings. This was different from the regular process of demolishing as they changed their internal business model towards the retaining of material value and adding more value by returning these building materials and products in different life-cycles. At first, they were the owner of these harvested materials, but due to not enough knowledge on the specific details of materials new external parties were introduced to the process to help them with the proper circulation of these materials. Thus, partnerships were established to support the internal processes of the Dismantler A. In addition, a knowledge centre has been set up internally, for the purpose of sharing information on innovative projects and activities taken internally per project.

> "*We as a company started six years ago by harvesting buildings. We do not call it demolishing, as we are retaining and adding value of the materials in the buildings.*" — (Dismantler A, personal communication, April 8, 2021)

Dismantler B internal alignment is directed towards the observation of the entire value chain and implementation of circular solutions. The business model is directed towards the retaining of harvested materials into other life-cycles by adding more value to them through direct reuse, re-manufacturing or recycling.

Cross-chain collaboration

In order to coordinate all the operations and processes of Dismantler A, partnerships have been established with external parties. These partnerships were necessary as the internal company had not advanced knowledge on the re-purposing and re-manufacturing processes needed to the harvested materials. Partnerships have been identified with suppliers, logistic service distributors and knowledge companies that help support innovative researches, such as the re-purposing of concrete. Now the harvested materials are sold to these partners, and agreements are in place to ensure the material is re-purposed and distributed correctly.

> "*We have several business cases with different partner, to whom we bring the materials and then they sell the as a new circular product. These partnerships are different, as sometimes some materials can be directly reused, while others like concrete re-manufacturing is needed. In those cases we have coalliance with these partners to help them in their processes and bring the new product to the market together.*" — (Dismantler A, personal communication, April 8, 2021)

Similarly, Dismantler B also has proactively established external collaborations with a set of partners. There has been an increase of interest on the application of circular principles. Therefore, together with their external partners Dismantler B researches and analyses buildings and their disassemble possibilities in order to directly reuse or re-purpose the harvested material and add value to them.

> "*Circularity is becoming more important. Many project developers, building companies, architects want to be involved in circular building, either because they want to themselves or because they have to. Or because they feel they have to in a few years, and they want to learn now so they can operate in a few years. By doing what we do now we get new business and partners, because we operate in a circular way.*" — (Dismantler B, personal communication, April 21, 2021)

Information exchange

The willingness to share information is high for Dismantler A. This is seen by the creation of an internal knowledge centre. This willingness is also observed to be high within the projects undertaken, in order to align all stakeholders towards a circular building objective. However, there are also barriers observed to this willingness. The information is mainly shared between the established partnerships, and some resistance is noticed to share information with competitors, as a competitive advantage wants to be maintained. Contrarily, Dismantler B argues that they are willing to share their information and how they operate with third-parties, as they want to inspire more companies to join them in this mission. From Dismantler's B experience the main barriers in information are noticed in regards to financial transparency of the produced building materials/products.

> "*Actually the circular hubs are meant as a place where we can invite people and show what we are doing. Thus, we are more than willing to share information and knowledge with others, because we want to change the whole sector and not be the only ones in this field. However, we are reserved with companies that are our direct competition.* " — (Dismantler B, personal communication, April 21, 2021)

The information systems used by Dismantler A internally are Oxcart and own platform system. These systems hold information on the materials harvested and the building components per project. No specific information systems are identified by Dismantler B.

6-10-3 Control environment

ICT architecture requirements & functionalities

Functionalities identified by Dismantler A encompassed the ability to be accessible by different stakeholders to a certain extend first, this limited accessibility is achieved by a safe and secure system. Another important functionality for Dismantler A is the ability to not only store information on materials, but also evaluate them and their performance. Dismantler B on the other hand, emphasised the data exchange ability. In addition, ability to provide correct information and on time.

> "*It's the validation of materials that is a big issue for us, as we have not built or maintained the buildings. Thus we know absolutely nothing about the product and we cannot guarantee its performance.*" — (Dismantler A, personal communication, April 8, 2021)

Control facilitators across supply chains

Dismantler A suggests their own function as a potential facilitator of a control centre. This is due to their over-viewing position of the deconstruction of the building and the arranging of distribution of the harvested materials to storage places or to their partners. On the other hand, Dismantler B argues that a facilitator of a control centre should be fully independent, either a new entity or a governmental body, without any links to commercial companies. If a commercial company has control over such a tool, it would create hesitation for other companies to share their information.

> "*Maybe the control environment should be digital where different software is interconnected with each other.*" — (Dismantler A, personal communication, April 8, 2021)

> "*I think that it should be a complete independent company. If the control has any link with a commercial company, others will hesitate to share information.*" — (Dismantler B, personal communication, April 21, 2021)

Circular building tools integration

Dismantler A has identified several circular building tools used to facilitate their operations, such as the Environmental Cost Indicator, Circularity Index, MPG calculation. The use of these tools have shown to be beneficial because through the calculations Dismantler A is able to verify that they are complying with the regulations put by the government and that they are towards the goal of becoming a circular built environment. While Dismantler B makes use of the Cirdax tool, which assists in the creation of material passports.

6-10-4 Social environment

Legal, financial and cultural factors

From a legal point of view Dismantler A identifies some regulations in regards to the MPG calculations. The government requires a specific standard on different calculations, which is enhancing more companies to take into consideration circular principles. Although, Dismantler A argues that more regulations are needed to align more companies towards the circular goal, it is also understandable why there are no strict regulations. From a financial point of view, the current companies are not able to transform within a short amount of time their linear business models to circular as they could potentially go bankrupt. Dismantler B argues that financially a circular project is more expensive than a traditional one. Therefore, it is needed for manufacturers to be transparent on building product details.

The financial factors and the lack of regulation makes the change of the cultural mindset harder. Dismantler A argues that to establish a circular supply chain, besides dealing with materials, it is crucial to change the system thinking of the involved parties, starting with the designing in a more conscious way and creating accountability over the produced materials. Dismantler B addresses that most companies wait and just research on how they can be circular, while more actions need to be taken even if the delivered project is not entirely circular.

> "*There are some regulations on the calculations of MPG and in the next year are putting the bandwidth from 1 to 0.8. Although they can be harsher, I understand that it is hard. A lot of companies would go bankrupt, because they cannot adapt their processes as fast. However, I think the government can do more to pressure companies take more actions.*"
> — (Dismantler A, personal communication, April 8, 2021)

> "*The big difference between us and some of our competitors is that we take action and do not just talk about it. Sometimes this means that we fail, or what you are doing today is, let's say 40% circular instead of 100%. But we would rather do something today that is 40% circular, than talk for years about something that might or may not become 100%.*"
> — (Dismantler B, personal communication, April 21, 2021)

Table 6-9: Overview of case findings (Dismantler)

Analysis Variables	**Description per case**	
	Dismantler A	*Dismantler B*
Production environment		
Operation and process coordination	Operations and processes organised in-house through two collectives. First collective obtains all partnerships for direct re-distribution of materials. Second collective focuses in researching and developing innovative methods of re-manufacturing.	All processes and operations are coordinated in-house depending whether it is a new built or transformation project.
Circular reverse loops	Already facilitating a reverse loop through their process and operation coordination and overseeing the process. Stakeholders: Suggests the involvement of suppliers or sub-contractors earlier in the process. Process: The initiative phase of the project is considered as most crucial, to ensure stakeholder integration and circular decisions to be taken.	Already established reverse loops and overseer of the process. Stakeholders: Suggests the introduction of a 'performance certifier' for the harvested materials, to guarantee their quality. Process: The logistical part of the whole process is considered as crucial for the circulation of materials fast and swiftly.
Strategy integration	Change of mindset from demolishing to disassembly and circular principles are integrated in the form of harvesting materials, directly reusing them, re-manufacturing and recycling as a last resort.	Change of mindset from demolishing to disassembly and circular principles are integrated in the form of harvesting materials, directly reusing them, re-manufacturing and recycling as a last resort.
Organisation environment		
Internal alignment	Internal business model is focused in retaining and adding more value to materials by returning them in different life-cycles.	The business model is directed towards the retaining of harvested materials into other life cycles by adding more value to them through direct reuse, re-manufacturing or recycling.
Cross-chain collaboration	Established set of external partnerships, who are specialised on a specific building material and with who the main processes are executed.	A set of established external partnerships, but open for collaboration with other third-parties too.
Information exchange	Information is exchanged within the project's supply chain and external partners, to align all stakeholders towards a circular building objective. Barriers of information exchange: The information is mainly shared between the established partnerships as a competitive advantage wants to be maintained. Information system: Use of Oxcart and own platform system, that hold information on the materials harvested and the building components per project.	Willing to share information with third parties, in order to inspire more companies. Barriers of information exchange: Lack of financial transparency from stakeholders over the manufactured building products. Information system: not identified.
Control environment		
ICT architecture requirements & functionalities	A safe and secure system that is accessed publicly to a certain extent.	Data exchange ability with cross-chain stakeholders; ability to provide correct and on time information.
Control facilitators across supply chains	Suggests that the dismantler function could take this role, as they have an overview in the reverse loops.	An independent party or governmental body that has no links to commercial companies.

Table 6-9 continued from previous page

Analysis Variables	Description per case	
	Dismantler A	*Dismantler B*
Circular building tools	Environmental Cost Indicator, Circularity Index, MPG calculation; verify that they are complying with the regulations put by the government and that they are towards the goal of becoming a circular built environment.	Use of the Cirdax tool, which assists in the creation of material passports.
Social environment		
Legal, financial & cultural factors	Legal: Some regulations over calculations showing environmental impact, but still lacking and not enough to ensure action to be taken widely by companies. Financial: Harvest materials that are sold to third-parties, who then directly reuse or re-manufacture them. Cultural: It is crucial to change the system thinking and start implementing circularity since the design phases and create accountability over the produced materials.	Legal: No specific legal related elements were recorded. Financial: Harvest materials that are eventually stored in (temporary) storage units and re-manufactured there, and sold to third-parties. Cultural: Stakeholders should not wait to implement circular applications even if the building is not in its entirety circular.

6-11 Within-case Analysis of the Building Cases

In the previous sections, each of the interviewed cases has been thoroughly described. Most of the cases where described through the perspectives of two representatives within the same organisation type. Therefore, a within analysis should be conducted to investigate any similarities or unique characteristics of each individual case. The descriptive analysis approach of the cases enables for relationships between actions and effects to be found. The actions are related to the analysis variables of circular supply chains, while the effects are categorised based according to the four environments: production, organisation, control and social. The within-case analysis is done only for the cases with more than one representative.

Within-case analysis | Municipalities

The representatives of the municipality case were widely involved in investigating integration possibilities of circular principles in building industry, see Table 6-10. In addition, they were actively involved in researching different strategies facilitating projects towards a circular approach. A collaborative environment is established internally between different departments, regionally with other municipalities and locally with the city's market parties in supporting or impacting circular decisions within projects.

Table 6-10: Within-case analysis (Municipality)

Environments	Actions	Effects
Production environment	• The operation and process coordination of municipalities depends on the role that they have on a certain project (shaping, stimulating, regulating or capacity building). • Attempt to establish circular hubs and material passports per project. Believe that project integration is key and demolishing companies have a critical part into the return loops. • Both municipalities are taking initiative to study and initiate more circular processes within the built environment. It is observed that these strategies take the shape of regulations and guidelines that support the circular process strategies which narrow, slow-down or close resource loops.	• Have little influence over building projects due to no land ownership, but more influential to the public space. • Set an example on material passport utilisation and can facilitate the process through their program of requirements or other instruments i.e zoning/master plans. • Different strategies are analysed and the proactive mindset of the municipalities facilitates additional steps to be taken in regards to circular supply chains.
	• A set of ambitions are set towards the circular built environment.	• Ambitions are still qualitative and concrete actions and guidelines need to be established.

Table 6-10 continued from previous page

Environments	Actions	Effects
Organisation environment	• Have established collaborations regionally: with companies, knowledge institutes and municipal departments, locally: with the companies involved in a construction project and nationally within deals and agreements. • Due to their position in the process and aim to safeguard the public interest, willingness to share information and transparency is high.	• Through these collaborations, different perspectives are observed and more effective cross-chain collaborations are achieved. • Higher transparency demystify the concept of circularity and can lead to parties gaining knowledge on how to implement circularity in their projects.
Control environment	• Requirements and functionalities are required that create a safe and secure system that exchanges information that is filtered depending per situation. • Suggest the possibility of the control environment to be facilitate by a set of information systems which communicate with each other. • Investigating the different tools that are being released to the market and use of some of them internally.	• Safeguards sensitive information to be shared with anyone and maintains the competitive balance between the market parties. • Increases standardisation possibilities or the establishment of a common shared language regarding circular building. • Can assist in the establishment of regulations and other agreements or connectivity possibilities with other tools.
Social environment	• Proactively investigating possibilities in adding circular criteria into the tendering processes, lowering MPG regulation requirements and making agreements with market parties. • Provide financial incentives to companies who initiate circular building projects, through subsidies and other financial instruments. • Shift from reactive to a proactive mindset, with the help of regulations and incentives from the municipalities and publishing information of example projects.	• Stricter and clearer regulative environment directs market parties towards the achievement of circular ambitions. • Financial effects include more support towards private market parties and more initiatives to be undertaken. • Improved image and exposure to the market parties on how circular projects could be achieved.

Within-case analysis | Project Developer

The developer case provided insights in traditional stakeholders changing their business activities and acquiring circular-specific role (transformation agent) activities and developers maintaining the same role within the supply chain. In addition, the new role included the adaptation of supply chain processes, as well as new financial estimations to support these processes. On the other hand, the overview on the entire chain and willingness to exchange information remain rather traditional. An overview of the within-case analysis is provided in Table 6-11.

Table 6-11: Within-case analysis (Developer)

Environments	Actions	Effects
Production environment	• Internalise processes and operate in the design phase besides the developing processes. • Enable the reverse loop through both transformation projects and new-built. However, the returns happen in different moments in these two projects. • A circular supply chain is enabled when addressing not only new-built projects but also transformation and renovation projects of the existing built environment.	• Increase their influence on the development of the project. • Makes a distinction between the processes when dealing with a transformation project or new-built project. • Strategic implementation differs depending whether, an existing building is transformed or a new building is built.
Organisation environment	• Focused in coordinating and influencing the development phases of the project towards a circular built environment by aligning their internal processes towards this goal (for example: becoming an own investor). • Collaborations with a set of partners and with organisations to expand their knowledge. • The information exchange is coordinated by the developer in a rather traditional way and within the project by making use of BIM information system.	• By undertaking investor roles, the developer has more influence on the budget and decision-making moments of the project. • Supports the activities that are currently taken for circular building by having everyone on aligned to the same main goal. • Information exchange is still hindered by the ambition to maintain competitive advantage in the market.
	• Requirements and functionalities regarded the ability of different systems to quickly connect to either existing or new systems and support data exchange.	• Facilitates a better information sharing environment and less delays or miscommunications to happen.

Table 6-11 continued from previous page

Environments	Actions	Effects
Control environment	• Developers themselves were suggested as part of the control due to their central position in the chain or an independent party. • Mainly own tools were used with the exemption of Madaster for material passports and MPG calculation.	• The developer being in control that also has investor powers could direct the process towards the achievement of their own goals, while an independent party can maintain the unbiased control. • Mainly helps in the facilitation of internal control environment.
Social environment	• Regulatory environment does not support the concept of flexible and adaptable buildings. • Circular building is more expensive than building new, due to maintenance costs, other re-manufacturing needs and higher investments in the initiation phases. • Have taken a more proactive role, but do not feel supported by other developers and investors due to their reactive mindset.	• Are faced with resistance from banks to invest projects that are adaptable and flexible. • Financial effects increase and can affect the decision-making moments in a project process. Higher financial estimations should be made due to uncertainties. • The lack of support hindrances the development of circular building projects.

Within-case analysis | Project Manager

The project manager acted as the focal company that has an overview of the entire supply chain process phases (Table 6-12). As a central node between stakeholders and clients they bring them together and can influence projects by establishing trust and enabling information sharing between them. Strategic suggestions can be provided during the project and are able to overview the direction of the project due to being involved in all the phases.

Table 6-12: Within-case analysis (Manager)

Environments	Actions	Effects
Production environment	• Their operation encompasses the entire process from initiation to complex design and construction interfaces to the handover periods and the interim payments. • Attempt to involve more stakeholders in an integrated way and investigate how responsibility lines can be established. • It is believed that the current environment does not hold all the needed criteria to deliver a circular supply chain, but this is not a barrier to still implement small circular aspects into the project, such as design for disassembly strategy, or make conscious choices.	• Allows for suggestions to be given during the project and align the different stakeholders towards circular principles. • Collectively discussing enables for negotiations/consensuses to be made in the working agreements regarding circularity. • Strategies and proactive actions are still taken to implement some circular principles in the project.
Organisation environment	• Have embraced the importance of developing a circular supply chain and want to strengthen their innovation and knowledge position on the matter. • Traditional collaborations within the project process; with a set of external partners to share and develop new approaches. • Very willing to share information externally as the importance of circularity increases. However, scepticism from stakeholders is observed	• A proactive mindset towards the implementation of circular supply chains helps make a circular business model more tangible internally. • Supports the current activities due to every party being on board. • Their willingness to share information can be hindered by the lack of support from other parties.
Control environment	• Requirements and functionalities regarded the support of data exchange with different parties, while still providing a safe and secure system. • An independent entity that receives the required information from asset managers and building owners, should facilitate the control environment. • Use of several different circular tools from the market or from own developments.	• Facilitates the storing and exchange of data at any time when needed to external companies. • Avoids bias and parties focusing on personal ambitions and goals. • The tools address very specific data details of materials and do not address the process as a whole.
Social environment	• Request for a regulatory environment that instruct for a certain percentage of secondary materials to be used. • Circular building is more expensive than building new, due to maintenance costs, other re-manufacturing needs and higher investments in the initiation phases. • Stakeholders are more reactive to client demand than proactive towards implementation of circular principles.	• Stricter regulations enhance initiatives undertaken towards circular building. • Financial increases to the process, and budget estimations may require different approaches. • The lack of project integration in the initiation phases results in little impact possible from the parties involved in the later phases

Within-case analysis | Designer

The designer part of an action team for circular design, integrates circular principles and strategies that enable a circular design. The collaboration with other designers allows the action team to propose and research strategies that are widely accepted by different designers and stakeholders, see Table 6-13 for additional information.

Table 6-13: Within-case analysis (Designer)

Environments	Actions	Effects
Production environment	• To enable a circular building, the processes and operations need to include new strategies and actions in the design phase, to be passed on to the other phases. • The design phase needs to integrate actors active before and after the design is made, for addressing appropriate circular strategies for the project. • The designer team has identified six strategies which are explained and examples are given.	• Effects on the building process imply that the design will have a bigger impact on the progress of the progress phases. • Facilitates a more integrated design phase where different stakeholders come together and align their ambitions. • The strategies implemented define how the other phases of the project process will be executed.
Organisation environment	• Within the action team the designers are separate units as they belong to different companies. • Established collaboration with around 60 other designers, architects and contractors. • The strategies, examples and other are publicly shared with external parties.	• Effects on internal processes of the designer's respective companies as they bring the work agreements and strategies established with them. • Effects imply that different perspectives of designers are gathered and merged, and gives more choice options on the strategies that could be undertaken by others. • Effects of being transparent and sharing knowledge, imply that the concept of circular design is more clear and more designers can initiate such designs.
Control environment	• Tools should provide an overview of the inventory of available materials and products; compare options.	• Effects on such functionalities of the control environment enable the most appropriate choice for the project at hand to be made.
Social environment	• Request for a regulatory environment that has clear guidelines. • Parties operating in the financial markets, such as banks, insurance companies or pension funds, are becoming more interested in creating conditions and possibilities to finance circular projects. • Attempts to change the cultural mindset of designers by demystify the concept of circular design through examples and some suggestive guidelines.	• Stricter regulations to ensure actions and initiatives to be undertaken towards circular building. • Financial support can encourage more market parties to undertake circular building projects. • Effects imply that these guidelines may not be accepted by other companies and representatives who were not involved in the process.

Within-case analysis | Contractor

The contractor case has internalised the construction process phases. A strategic collaboration has been established with a set of suppliers and manufacturers that deliver products and materials to the different projects. In addition, the entire process is centrally controlled and sometimes the design phases are also undertaken. Both contractors understand the importance of embracing circular strategies, which has lead to the establishment of a circular hub that operates within the company boarders. However, both focal companies still are highly influenced by the aim to maintain their competitive advantage in the market (Table 6-14).

Table 6-14: Within-case analysis (Contractor)

Environments	Actions	Effects
Production environment	• The businesses and production processes are integrated in-house based on partnerships with several sub-contractors and suppliers. • Investigating solutions that enable fast-movement of materials and include the deconstruction process in house. • Strategies deal with the circulation of materials and internal establishment of a circular hub.	• The processes oversee the construction processes and sometimes design phases, and are coordinated centrally. • Demystifies the circular activities within company boundaries, and can act as an example to others. • Assists to internally establish a circular approach.

Table 6-14 continued from previous page

Environments	Actions	Effects
Organisation environment	• The internal alignment goes beyond the traditional processes by integrating concepts like sustainability, safeguarding quality, digitisation and modern employment relationships. • Collaboration follows the traditional methods lied down in contracts and agreements and with a set of partners. • Oversee the exchange of information between the different stakeholders and mainly shared within projects and established partners.	• A clear internal alignment towards circularity supports more initiatives to be undertaken. • Supports the current activities due to every party being on board and sharing similar goals. • Little knowledge sharing with external companies that are not involved in the same supply chain.
Control environment	• Requirements and functionalities regarded the support of data exchange with different parties through some filters, timely and correct information. • Suggest an independent entity as facilitator of the control environment. • Use of several different independent circular tools from the market.	• Coordinate cross-chain information flow, maximise logistical distribution. • Avoids bias and parties focusing on personal ambitions and goals. • No coherence or connectivity between the tools.
Social environment	• Request for a regulatory environment that has clear guidelines. • Highly important to keep their competitive advantage in the market. • Projects are highly influenced by client demand, who have little demand over circular building.	• Stricter regulations enhance initiatives undertaken towards circular building. • Financial benefits are important, thus contractors comply to client demand, which often does not include circularity. • Main initiation towards circular building is taken by own initiative.

Within-case analysis | Supplier

The supplier case acted as the focal company and have integrated their processes with other producers and manufacturers resulting in the development of an integrated product/service coordinated by the lead supplier (Table 6-15). The integrated product is installed and retrieved by the lead supplier and aims to prove that financial profits can be achieved from standardisation and return agreements.

Table 6-15: Within-case analysis (Supplier)

Environments	Actions	Effects
Production environment	• Processes are organised in such a way that facilitates the development of an integrate product for the infill of a building. • The supplier has aligned their business processes to enable the establishment of reverse loops through contracts and agreements. • The supplier has established a responsibility line with its partners and the materials that they produce.	• Effects on the building process imply that there is a higher integration between suppliers and manufacturers. • Facilitates circularity and re-purpose of materials in other life cycles. • This strategy influences manufacturers to become more conscious on the production of the material/product.
Organisation environment	• The processes of the supply company are still separate besides the centralised engineering of the integrated product. • The supplier is in constant collaboration with a fixed number of other suppliers and manufacturers that provide the materials needed to deliver the integrated circular kitchen service. • The lead supplier is in charge of the information flows between their partners and other stakeholders and in charge of providing the material passport of the products delivered in projects.	• Effects on internal processes of the supplier result in increased productivity in and efficient site installation and deconstruction. Supports the current activities due to every party being on board. • Effects of being transparent and sharing knowledge, imply that more stakeholders are able to undertake such activities.
Control environment	• Tools should allow for data exchange, transportation of products and building components to appropriate stakeholders and hold material passports. • An independent entity or governmental body should facilitate the control environment. • Use of several different circular tools from the market or from own developments.	• Effects on such functionalities of the control environment enable for the correct information to be delivered to the appropriate stakeholders and correct re-purposes to happen. • Avoids bias and parties focusing on personal ambitions and goals. • The tools address very specific data details of materials and do not address the process as a whole.
	• Request for a regulatory environment that has clear guidelines. • The legislations mainly support the production of non-circular products, as the taxes on them are cheaper than circular products.	• Stricter regulations to ensure actions and initiatives to be undertaken towards circular building. • Additional taxes or financial requirements to produce, deliver and retrieve circular products hindrances initiatives.

Table 6-15 continued from previous page

Environments	Actions	Effects
Social environment	• Attempts to change the cultural mindset of manufacturers and other suppliers by acting as an example of how an integrated product can be delivered and returned in other life cycles.	• By providing examples the circular supply chain processes are more tangible and encourages more suppliers to change their processes.

Within-case analysis | Logistic service provider

The logistic service provider case emphasises the need of information sharing and collaboration between different service providers. By establishing a cross-chain collaboration with other providers and stakeholders, efficient distributions streams are enabled (Table 6-16). Optimal routing is achieved from a central control by a control tower, which facilitates collection, deliveries and returns of waste streams.

Table 6-16: Within-case analysis (Logistic service provider)

Environments	Actions	Effects
Production environment	• The operations and processes are coordinated based on three main aspects that aim to guide the constriction team from the tendering to the delivery moment, towards efficient logistical distribution streams within a project. • The logistic service provider are continuously investigating possibilities on how to create more optimal routing of planning of logistics for the waste streams and returns.	• Effects on the building process imply centralised control of logistical distributions, allow for more efficient planning. • Coordination with delivery and pick up for returning materials contribute to optimal routing and less carbon emissions.
Organisation environment	• Their internal control tower oversees the different agreements, planning and potential disruptions in case of unforeseen developments. Internal coordination through a control tower. • Through a top-down approach, the logistic service provider brings parties together and coordinate plans and time schedules that are appropriate to achieve the desired results. • The focal company is internally aligned in a way that allows to support information exchange about construction logistics between the different stakeholders.	• Internal coordination of the different agreements with other logistic providers allow for efficient execution of business activities. • Cross-chain collaboration implies circulation of materials and products to appropriate parties and projects. • Effects of being transparent and sharing knowledge, imply that more stakeholders are able to undertake such activities.
Control environment	• Tools should allow for data exchange ; maximise logistical distributions efficiency qua timing and planning. • The logistics specialist as they guide the construction team in the efficiency drive of the total logistics surrounding a project.	• Effects on such functionalities of the control environment enable for the correct information to be delivered to the appropriate stakeholders and correct re-purposes to happen. • Ensures that the agreements made are enforced and navigates materials and products between the suppliers, manufacturers, contractors.
Social environment	• Project budgets should include financial estimations on creating a control environment, or hiring a logistical specialist. • Behavioural changes are needed in regards to information sharing and ways of working were materials are released and collected on site at least one week before collection and distribution plans.	• Could assist in a more efficient and optimal planning and execution of material and product distribution. • Effects on these behavioural changes imply that materials are collected on time and distributed optimally to other projects or suppliers.

Within-case analysis | Dismantler/Demolisher

The dismantler/demolisher case proves that traditional stakeholders can adapt and implement business activities that align with those of circular roles (dismantler specialist). The once demolisher companies have transformed their business model and undertake new processes of analysing and deconstructing existing buildings (Table 6-17). The deconstruction, sorting of materials per re-purpose ability is harmonised with the transport routes to either a circular hubs or to producers who are capable of re-utilising them.

Table 6-17: Within-case analysis (Dismantler)

Environments	Actions	Effects
Production environment	• All processes and operations are coordinated in-house depending whether it is a new built or transformation project. • Have integrated a reverse loop through their process and operation coordination and overseeing the process of it. • Change of mindset from demolishing to disassembly and circular principles are integrated in the form of harvesting materials, directly reusing them, re-manufacturing and recycling as a last resort.	• The processes oversee the post-use phases, and are coordinated centrally to enable the start of new cycles. • Demystifies the circular activities within company boundaries, and can act as an example to others. • Traditional stakeholders are evolving towards new business models that align with the circular needs of the building industry.
Organisation environment	• The business model is directed towards the retaining of harvested materials into other life cycles by adding more value to them through direct reuse, re-manufacturing or recycling. • Established set of external partnerships, who are specialised on a specific building material and with who the main processes are executed. • Willing to share information with third parties, in order to inspire more companies. Information usually shared between partners, but still no full transparency from stakeholders over the manufactured building products.	• Internal establishments and circular business models, lead to initiatives to be taken and involvement of more companies too. • Supports the current activities due to every party being on board and sharing similar goals and working agreements being established, leading to accountability • Little knowledge sharing with external companies that are not involved in the same supply chain due to maintaining competitive advantage.
Control environment	• Requirements and functionalities regarded the support of data exchange with different parties through some filters, timely and correct information. • Suggest that the dismantler function could take this role, as they have an overview in the reverse loops or an independent party/ governmental body that has no links to commercial companies. • Use of several different independent circular tools from the market.	• Coordinate cross-chain information flow on time and updates to happen. • Avoids bias and parties focusing on personal ambitions and goals or due to a better overview of dismantlers in circular reverse loops. • Act as a verification mechanism to the business activities undertaken.
Social environment	• Request for a regulatory environment that has clear guidelines. • Harvest materials that are eventually stored in (temporary) storage units, re-manufactured and sold to third-parties. • Attempt to facilitate the implementing of circularity since the design phases and create accountability over the produced materials.	• Stricter regulations to ensure actions and initiatives to be undertaken towards circular building. • New financial models have been established to make profit for additional work from deconstruction. • Encourage actions to be taken even if it does not result in a circular project in its entirety.

6-12 Cross-Case Analysis between the Building Cases

The cases have been individually analysed, and in some cases with over one representative the within-case analysis has been done. A cross-case analysis aims to confront the findings between the different organisation types, in order to identify similarities and differences. An overview of all the findings has been provided in Table 6-18.

Cross-case similarities on MCSCM perception

The majority of the cases the representatives recognised the importance of implementing circular principles in their internal processes and operations. Most of them have already adapted their processes towards the creation of a circular built environment, and others had recently started doing so. The companies that had more years of experience with these adjusted operations were noticed to have internally applied circular operations themselves or via an established collaboration with other supply chain partners. In contrast, the less experienced were focused into further researching internally. Besides the tendency to internalise, in all cases the organisations have an established collaborations either legally or due to past collaborations, with a specific set of partners. In addition, almost all cases claimed that from a financial point of view circular building is more expensive then traditional building, and that they were faced with traditional stakeholders expecting the opposite. The legal dimension was also described by all cases as lacking in regulations and agreements that could incentivise more companies to take action. Another similarity was noticed in the cultural dimension, where the majority recognised that to enable a circular supply chain requires a change of mindset from the stakeholders.

In regards the *circular building tools* when asked on their benefits and limitations, most cases identified the tools as lacking in connectivity or capturing the essence of circularity. In the same topic, Madaster and the BIM information system seem to be the two overarching systems to be frequently used by different stakeholders. Furthermore, although there were some slight differences between cases, the majority found the functionality of a 'secure & safe system which allows data exchange with some filtering' important. The filtering is supposed to restrain the public accessibility of data to a certain extent.

Cross-case differences on MCSCM perception

The cross-case analysis also pinpointed some differences between the cases, which mainly represent the different approaches of the companies toward applying circularity. The observed *municipalities* were still researching how to translate their ambitions to concrete actions, regulations or agreements. The *project developers* aimed at coordinating their processes in such a way that influenced the development phases of the project towards a circular built environment, and sometimes taking over other activities like being own investors. The *project managers* were investigating on how to bring everyone to the table and steer the project towards a circular building and create a stronger integration between the design and construction phases. The *contractors* mainly aimed at increasing the levels of prefabrication and modular approaches, while coordinating the entire construction process. The *suppliers* focused on the production and delivery of a fully-integrated infill product as a service. The business model of the *dismantling companies* aimed at the harvesting of existing building materials and re-purposing them in different manners.

Beside the approach of internally integrating activities into their own organisations, collaboration is also noticed to happen. It is observed that there is a tendency for the collaboration to be in the form of separate organisation units in which joint business activities take place. Collaboration was also noticed to happen based on legal agreements, such as in the case of the supplier.

Although all cases found the sharing of information as crucial, their willingness to share information differed. Some companies were open to share their knowledge and way of working, in order to inspire and attract more companies to undertake similar activities. In addition, from the perspective of municipalities due their position of serving the public interest and requires them to be as transparent as possible. However, it was observed that the willingness to share information was higher within the established collaborations, rather than with external parties with whom no agreements or partnerships were formed.

Apparently, the analysed cases also had different understandings on the concept of circular supply chains. Some focused on the material flows and the possibility to establish accountability lines. Others, claimed that accountability lines cannot be established due to the time element and building owners or other parties had to take initiative for the returns of materials flows. In addition, each case had their own vision about which organisations should be involved. Some suggested the introduction of new stakeholders, i.e. a performance certifier, salvage dealer or reclamation expert, which would serve the ultimate purpose to providing a guarantee the performance of harvested secondary materials. However, it is noticed that most traditional stakeholders could undertake some of the specific circular stakeholder activities, such as the case of demolishing companies becoming dismantlers, or developers undertaking the role of a transformation agent.

In the previous section the two overarching circular tools were identified. However, it was noticed not only cross-case, but also within-case there were different circular building tools used. The reason to this, is either due to the different operation and processes that each case conducts, but also due to the oversupply of tools with a similar purpose. Cases recognised benefits either in the shape of receiving competitive advantage in tendering moments or as a confirmation their internal processes were properly aligned.

6-13 Reflection on key aspects of this chapter

This chapter started by first introducing the reasoning behind the choice of the selected cases. Then, the cases were individually described and main findings were collected in a tabular representation. The description of the cases through the same set of variables derived from the analytical model, enabled for the within- and cross case-analysis of the building cases to be done. The within-case analysis identified the effects that the actions of the cases had on the four environments under inspection. The, a cross-case analysis was conducted in order to identify underlying similarities and differences between the cases.

When confronting the findings among the different organisation types, fundamental differences were noticed mainly due to the different business alignments between the cases. The scope and level of circular implementation is noticed to depend on the organisation type and their position in the process. In general, the processes still seem to be fairly detached and following the linear approaches. The current situation of a circular supply chain is still ambiguous due to the different understanding of stakeholders and lack of a common language. In addition, the control environment is overpopulated by different information systems and tools, which act individually and currently do not assists collaboration between each other. In the last years, there have been more building project examples, which are helping to conceptualise the changes of processes in a more integrated way and the different requirements when implementing circular principles.

The findings from this chapter conclude the empirical analysis and the testing of the theoretical variables. In the following chapter, the theory and the findings of this chapter will be taken into consideration and translated into a model, that provides an overview of th whole circular supply chain environment

Table 6-18: Cross-case analysis of the building cases

Areas of Analysis	Case: Municipality	Case: Project developer	Case: Project manager	Case: Designer	Case: Contractor	Case: Supplier	Case: Logistics service provider	Case: Dismantler
Production environment								
Operation & process coordination	The operation and process coordination of municipalities depends on the role these municipalities have on a certain project (shaping, stimulating, regulating or capacity building). Have little influence over building projects due to no land ownership, but more influential to the public space. Adjusting processes and their operations to include circular principles, through tender requirements and other incentives.	Internalise processes and operate in the design phase besides the developing processes.	Their operation encompasses the entire process from initiation to complex design and construction interfaces to the handover periods and the interim payments, which allows them to suggest the use of secondary materials in projects.	The designer acknowledges the change of processes to meet the circular building requirements. These changes depend on the strategies that are chosen and the project processes are adjusted accordingly.	The businesses and production processes are integrated in-house based on partnerships with several sub-contractors and suppliers. The processes oversee the construction processes and sometimes design phases, and are coordinated centrally through an open-source approach.	The process operations are coordinated mainly by the lead supplier towards circular principles. Starting with the designing process to the products being leased or sold with a buy-back agreement, to the product being recovered and returned to original manufacturers.	The operations and processes are coordinated based on three main aspects that aim to guide the constriction team from tendering to delivery moment, towards efficient logistical distribution streams within a project. Coordination centrally through a control tower.	All processes and operations are coordinated in-house depending whether it is a new built or transformation project.
Circular reverse loops	Attempt to establish circular hubs and material passports per project. Believe, project integration is key and demolishing companies have a critical part into the process.	Enable the reverse loop through transformation projects, which integrating a big team, while new-built still follows the traditional project phases. In both cases technical information of materials is key. Suggestion of introducing a reclamation expert.	Design for disassembly and use of bio-based materials are identified as two crucial components in the establishment of such loops. Attempt to involve more stakeholders in an integrated way and investigate how responsibility lines can be established.	The designer is researching possibilities to enable such loops since the design phase. Stakeholders: The design phase needs to integrate actors active before and after the design is made, for addressing appropriate circular strategies for the project. Information: The monitoring, measuring performances and sharing information is crucial, in order to estimate past successes and mistakes.	Want to established relationships with different construction companies to enable fast-movement of materials and include the deconstruction process in house. Important to have technical details over the building materials and products available from the building owners.	The lead supplier has already aligned their business processes to enable the establishment of reverse loops from leasing and take-back agreements. Suggestion to introduce a circularity salvage dealer or reclamation/dismantling expert that ensures the products are returned to other life-cycles.	The logistic service provider are continuously investigating possibilities on how to create more optimal routing of planning of logistics for the waste streams	Already facilitating a reverse loop through their process and operation coordination and overseeing the process of it. Suggests the involvement of suppliers or sub-contractors earlier in the process and the introduction of a performance certifier. The initiative phase of the project in which stakeholder integration and circular decisions are taken, and the logistical part of the whole process is considered as crucial for circulation of materials fast and swiftly.
Strategy integration	Circular building and especially supply chain is the process that maintains and extends the life-cycle of products/materials and the minimisation of the footprint by eliminating waste by adding value to the chain.	A circular supply chain is enabled when addressing not only new-built projects but also transformation and renovation projects of the existing built environment. It is expected to provide a steady financial income due to the building becoming modular and components being considered as a service.	It is believed that the current environment does not hold all the needed criteria to deliver a circular supply chain, but this is not a barrier to still implement small circular aspects into the project, such as design for disassembly strategy, or make conscious choices.	Within the designer team six design strategies have been identified: (i) preventive designing, (ii) designing for life cycle impact reduction, (iii) designing with recycled materials strategy,(iv) designing for future-proof, (v) designing with secondary materials, (vi) designing with renewable raw materials.	Circular supply chain is seen to have its start since the design phase (design for disassembly). Special focus on the circulation of materials and internal establishment of a circular hub.	The supplier emphasised the importance of establishing a responsibility line between the suppliers or manufacturers and their products.	No strategy integration in regards to circularity were properly recorded.	Change of mindset from demolishing to disassembly and circular principles are integrated in the form of harvesting materials, directly reusing them, re-manufacturing and recycling as a last resort.
Organisation environment								
Internal alignment	Both municipalities have identified a set of ambitions towards the circular built environment. Focusing on turning these qualitative ambitions to concrete steps, through regulations, agreements and incentives.	Focused in coordinating and influencing the development phases of the project towards a circular built environment by aligning their internal processes towards this goal (for example: becoming an own investor).	Have embraced the importance of developing a circularity and want to strengthen their innovation and knowledge position on the matter.	The designer is focused in the action team that investigates and reaches working agreements in regards to circular design. Collectively discussions, researches and working agreements are established for a circular design, which contributes to the whole organisation ambition of understanding and implementing circular building in practice.	The internal alignment goes beyond the traditional processes by integrating concepts like sustainability, safeguarding quality, digitisation and modern employment relationships.	Mainly focused in developing products for the infill of a building as service.	The focal company is internally aligned in a way that allows to support information exchange about construction logistics between the different stakeholders.	The business model is directed towards the retaining of harvested materials into other life-cycles by adding more value to them through direct reuse, re-manufacturing or recycling.
Cross-chain collaboration	Have established collaborations regionally: with companies, knowledge institutes and municipal departments, locally: with the companies involved in a construction project and nationally within deals and agreements.	Collaborations with a set of partners and also with organisations to expand their knowledge.	Traditional collaborations within the project process; collaboration with a set of external partners to share and develop new approaches.	The action team the designer is part of, consists of a collaboration between around 60 people that come from various companies and are involved with designing tasks within the chain.	Collaboration follows the traditional methods lied down in contracts and agreements	The supplier is in constant collaboration with a fixed number of other suppliers and manufacturers that provide the materials needed to deliver the integrated service	Through a top-down approach, the logistic service provider brings parties together and coordinate plans and time schedules that are appropriate to achieve the desired results.	Established set of external partnerships, who are specialised on a specific building material and with who the main processes are executed. Open to make more partnerships.
Information exchange	Due to their position in the process and aim to safeguard the public interest, willingness to share information and transparency is high.	The information exchange is coordinated by the developer in a rather traditional way and within the project by making use of BIM information system.	Very willing to share information externally as the importance of circularity increases. However, scepticism from stakeholders is observed as they expect to loose advantage in the market and due to privacy and security reasons. Have an integrate BIM system which is connected to Madaster to generate materials passports.	Information sharing is considered as a critical element in the establishment of circular design and project. Differences observed between large and small scale projects; for instance, in a larger project stakeholders are more willing to invest in information technologies and sharing information due to the increased complexity.	Oversee the exchange of information between the different stakeholders and mainly shared within projects and established partners. Use of KYP, BIM, GIS and own information system holding data on the construction planning and orders. All system are connected around BIM.	The lead supplier is the owner of data and in charge of providing material passport of the products delivered in projects. They are willing to share the information with other stakeholders, as they believe transparency is key to a circular economy and want to attract more companies doing similar business.	The focal company is internally aligned in a way that allows to support information exchange about construction logistics between the different stakeholders.	Willing to share information with third parties, in order to inspire more companies. Information usually shared between partners, but still no full transparency from stakeholders over the manufactured building products. Use of Oxcart and own platform system, holding information on materials harvested and building components per project.
Control environment								
ICT architecture requirements & functionalities	A publicly accessible but yet safe and secure system that allows data exchange through a set of filtering and some critical data is only accessible by certain parties. Provides a common system language.	Quick connectivity ability to other ICT which allows for data exchange and facilitate event management between stakeholders. Include overview of legal requirements and financial aspects of the process.	A safe and secure system that allows for data exchange and is accessed to a certain extent publicly.	Material passports for the new developed buildings and respective data base is necessary; tools should provide an overview of the inventory of available materials and products; compare options to enable the most appropriate choice for the project at hand to be made.	Provide timely and correct information; Data exchange with filtering possibilities; Open for all supply chain organisations; coordinate cross-chain information flow; maximise logistical distribution of harvested materials.	Allow for data exchange, transportation of products and building components to appropriate stakeholders and hold material passports.	Requirements and functionalities encompassed the ability to create maximise logistical efficiency and allow for flexibility qua timing and planning. In addition, information exchange and transparency with the different logistics specialists was considered very important.	A safe and secure system that is accessed publicly to a certain extent and allows for data exchange with cross-chain stakeholders. Ability to provide correct and on time information.
Control facilitator across supply chains	Suggest the possibility of the control environment to be facilitate by a set of information systems which communicate with each other.	Developers themselves or independent party.	An independent entity that receives the required information from asset managers and building owners.	No information was recorded in regards to the facilitators of the control environment.	Suggests the contractor function could take this role, as they act as the focal point of communication between stakeholders, or an independent party to avoid possibility of a specific stakeholder focusing only on their own projects.	Governmental body or an independent party from the market.	The logistics specialist as they guide the construction team in the efficiency drive of total logistics surrounding a project. They ensure that the agreements made are enforced and navigates knowledgeably between the many stakeholders, and are in possession of control tower.	Suggests that the dismantler function could take this role, as they have an overview in the reverse loops or an independent party/governmental body that has no links to commercial companies.
Circular building tools	Use of Circularise, Insert platform and Circular IQ.	Use of Madaster, MPG calculations and other own tools.	Use of Madaster, BREAAM, INSIDE/INSIDE, EcoInvent, Idemat and the Nationale Milieudatabase and other own tools. Argue that the tools quite detailed while a well-established process is lacking.	No information was recorded in regards to circular building tools of the control environment.	Use of Madaster, which assists in the creation of material passports; BCI, MPG and LCA calculation techniques. Main benefit observed during tender processes and for internal calculations. Little coherence and no-connectivity possibilities are detected between the tools.	Use of Product circularity index (within BCI); Circulytics and LCA calculations.	No information was recorded during the interviews on the type of circular building tools used.	Use of Environmental Cost Indicator, Circularity Index, MPG calculation, Cirdax, that verify internally that they are complying with the regulations put by the government and that they are towards the goal of becoming a circular environment.
Social environment								
Legal factors	Proactively investigating possibilities in adding circular criteria into the tendering processes, lowering MPG regulation requirements and making agreements with market parties.	Regulatory environment does not support the concept of flexible and adaptable buildings.	Request for a regulatory environment that instruct for a certain percentage of secondary materials to be used.	The Designer recognises that government is active and has several ambitions towards a circular building industry. However, they are noticed to often contradict each other.	Do not feel supported by the regulatory environment.	Do not feel supported by the regulatory environment.	No specific legal information was mapped.	Some regulations over calculations showing environmental impact, but still lacking and not enough to ensure action to be taken widely by companies.
Financial factors	Provide financial incentives to companies who initiate circular building projects, through subsidies and other financial instruments.	Distinctive difference between a new-built and transformation project, as the latter require more costs in the initiation phases than new-built. Estimate their finances in a different way for transformation projects due to higher uncertainties.	Circular building is more expensive than building new,due to maintenance costs and other re-manufacturing needs.	Parties operating in financial markets, such as banks, insurance companies or pension funds, are becoming more interested in creating conditions and possibilities to finance circular projects differently.	Important to keep their competitive advantage in the market. Thus comply to client demand.	The legislations mainly support the production of non-circular products, as the taxes on them are cheaper than circular products.	Project budgets should include financial estimations on creating a control environment, or hiring a logistical specialist that could assists a more efficient distribution of materials within and cross chain.	Harvest materials that are eventually stored in (temporary) storage units, re-manufactured and sold to third-parties.
Cultural factors	Shift from reactive to a proactive mindset, with the help of regulations and incentives from the municipalities and publishing information of example projects.	Have taken a more proactive role, but do not feel supported by other developers and investors. Still a reactive mindset observed.	Stakeholders are more reactive to client demand than proactive towards implementation of circular principles. The lack of project integration in the initiation phases results in little impact possible from the parties involved in the later phases.	It is observed these guidelines may not be accepted by other companies and representatives who were not involved in the process.	Projects are highly influenced by client demand, who have little demand over circular building. Main initiation towards circular building is taken by own initiative.	The cultural mindset of the even their partners is still mainly towards linear processes.	It is observed that behavioural changes are needed in regards to information sharing and ways of working were materials are released and collected on site at least one week before collection and distribution plans.	Attempt to facilitate the implementing of circularity since the design phases and create accountability over the produced materials. Encourage actions to be taken even if it does not result in a circular project in its entirity.

PART III

SYNTHESIS

Chapter 7

The Modular Circular Supply Chain Model (MCSCM)

This chapter focuses on conceptualising all the findings into a modular circular supply chain model (MCSCM) to give a better understanding on the circular supply chain context. Thus addressing the research design question: *Making a design for a circular construction supply chain model, facilitated by a control environment.* Modelling provides the cognitive activity of a topic, which allows to conduct investigations, analysis of the results and provision of recommendations to the problem that is being taken into account. Based on the theoretical basis and empirical findings a final model is proposed in this chapter. It should be noted that this model has been in an iterative process of development, first based on the literature survey findings which was then tested and further developed based on the empirical analysis. Thus, the final proposed (MCSCM) is a compilation of information derived from part I and II of this thesis.

The chapter starts by first confronting the theoretical framework and its analytical variables to the empirical findings. This has led to determine relationships between the two and assists in the model development. Then, an introduction of the proposed model is provided, within which the levels of analysis are further explained. The levels are individually described in order to give a clear understanding of the details within them. The chapter will then use a real-world case as proof of concept where the model is adapted to this particular situation. Lastly, a reflection on the proposed model and key insights of the chapter is provided.

7-1 Confronting theory with empirical findings

Before the MCSC model is presented, the empirical findings from the building case study need to be confronted with theory. The theory identified four theoretical areas and eleven variables of analysis, which were also used for the description of the building cases. For each of the variables the theory and the empirical findings are displayed in a tabular representation

(Table 7-1). This analysis has led to the identification of relationships between the theory and empirical, whether theoretical assumptions are supported by the practice view.

Table 7-1: Confronting theory with building case empirical findings

Analysis variables	Theory	Building cases	Relationship
Production environment			
Operation and process coordination	• Organisations in the supply chain should coordinate their processes and operations to achieve flow, and increase the effectiveness and efficiency of a circular delivery process. • The production flow can be understood as the flows of materials and operations, within which coordination of the supply chain is intensified. • The production flows are particularly focused in the reduction of waste and increased resource efficiency. • Decision-making moments will need to consider whether use of raw of materials is refused or reduced and secondary materials are used.	• In most of the interviewed cases internalisation has been mainly found and controlling of the adjacent phases is done. • The processes and operations that each cases conducted is dependent on the function that they hold within the supply chain, i.e demo/dismantlers having processes that enable the dismantling of products from the building. • Some cases also identified that attention is being given to collaboration of processes and delivering of an integrated product or service.	Circular production flows require the integration of processes and operations that could result in the delivery of an integrated product or service, which enhance return loops to happen.
Circular reverse supply chains	• The functioning of circular supply chains requires new processes that enable the recovery and returning of products and materials, by open or closed loops, into new life-cycles. • A reverse supply chain could be either open loop (recovery and returns to third party producers), or closed loop (recovery and returns to original producers). • At the moment the recovery of products and materials is mainly done at the end-of-life of these products, which results in the only down-cycling option. • The recovery process also makes use of additional energy and polluting emissions due to extra logistical matters of transporting and subsequent treatment of the recovered products.	• The majority of the cases focuses in first changing the operations and processes internally rather than within the entire supply chain, due to companies requiring to understand the processes first themselves. • For reverse loops to be established attention for this should be already put in the initiation and operation phases. • Transparency and material passports of the building are seen as crucial components. • The supplier and dismantler cases provided the example of the reverse loops to be achieved through contractual agreements with a set of partners they collaborated with.	The reverse loops have been recognised as crucial to circular supply chains. Depending on the position the companies hold in the supply chain companies address these returns in different ways.
Strategy integration	• The production processes incorporate circular strategies that contribute to the narrowing, slowing down and closing resource loops running through supply chains. • Circular building understands the industry from a restorative and regenerative perspective, thus creating a disassociation from the classical linear process. • The notion of "take, make, waste" is challenged, by returning possible products/materials in other project life-cycles. • Consequently, transforming the 'waste' component to three action fields: 'distribute', 'use' and 'recover'. • Circular strategies should aim to narrow, slow-down or close resource loops.	• Most cases had their own understanding of circular building and the strategies that were being implemented. • The vision and strategy implementation towards circularity differs even within the same organisation type. • Attention was mainly provided to strategies that enabled the narrowing of resource usage in building projects and some attention to the closure of resource loops. • Consequently, little strategies were being applied to slow-down the deterioration during the operational phase.	Application of circular strategies that narrow, slow-down and close resource loops fosters to change the approach of how the products are delivered through the supply chain.
Organisation environment			

Table 7-1 continued from previous page

Analysis variables	Theory	Building cases	Relationship
Internal alignment	• The focal company is required to internally align their business activities towards circular supporting ones. • Circular building requires the development of new business models that include and support internal circular business activities, which differs from the traditional ones. • By establishing internal circular business models, circular features in building supply chains are stimulated and enhanced, which can be further complemented by smart technologies. • It is observed that new circular-specific stakeholders should be introduced in the process, and collaborate with the traditional ones.	• Almost all the cases have recognised the importance of transitioning towards a circular building process and want to strengthen their innovation/knowledge position on the matter. • The internal alignment towards circular implementation in the focal company differs even within the same organisation type. • Each case has their own way approaching circularity internally and in building projects, whether these be through the used tools, or strategies implemented. • In a few cases some of the traditional stakeholders are adapting their internal alignment and processes that cover the operations of the circular-specific stakeholders.	Internalisation of business activities within companies makes the circular business model more tangible. This increases the control over the activities that facilitate an overall circular supply chain. In addition, it helps with sharing experiences and examples to other companies.
Cross-chain collaboration	• Cross-chain collaborations should be established between different organisatio within the supply chain through strategic/contractual agreements. • Collaboration can be either internal within company boundaries or cross-chain. • Cross-chain collaboration can either b horizontal (between project stakeholders or vertical (between different supply chains). • Horizontal collaboration must be facilitated by vertical collaboration to be effective.	• The majority of the cases focus on internalising the processes and demystify a circular business model, that complies with circular implementation, rather than collaborate with other companies. • Cross-chain collaboration mainly happens within a set of partners that the focal company has already established. • In a few cases the cross-chain collaboration still followed traditional methods, which were lied down in contracts and agreements.	Collaboration within and cross-chain help establish long-term strategic arrangements that improve the commitment and involvements of the companies in the supply chains.
Information exchange	• Organisations are required to increase their level of information sharing both within and beyond supply chain borders. • The exchange of information relies on the availability and willingness of information sharing, a joined information system or the integration of multiple ICT systems that are used by different stakeholders. • This requires trust and coordination within the involved stakeholders, leading to the need of governance models.	• Almost all cases recognise the importance of sharing information and knowledge within the supply chain. • Willingness to exchange information is dependent on the position the organisation holds in the supply chain; municipalities are more willing than contractors due to their aim to safeguard the public interest. • Information exchange differ per internal alignment; different systems are used or the way knowledge is shared depends on the organisation type.	Information exchange is crucial for the development of a circular built environment. Commitment of companies to share information enhances an integrated way of working, transparency and efficiency of circular supply chains.
Control Environment			
General control requirements	• A control environment is required to have a modular structure, enable coordination, collaboration and quickly connect to systems, whilst managing the relationships and risks within the supply chain. • Modular structures act as independent modules that can be used and adapted in different situations. • Coordination and collaboration are two crucial components when dealing with a multi-actor network. • Both quick connection and disconnection capabilities to external partners are needed for the optimal control environment. • Trust can be potentially built with mechanisms that provide past performances and relationship history. • High quality semantic standards are required to avoid the risk of misunderstandings.	• The building cases agreed with the requirements that theory identifies. • Additional requirements included is the development of a common language that could enable a better connectivity of the different tools, and the relationship management extending to holding the contractual and financial information of the project.	The theoretical requirements were approved by practice, and additions, where the creation of a common shared language within the different systems is critical to enhance the understanding of circular supply chains.

Table 7-1 continued from previous page

Analysis variables	**Theory**	**Building cases**	**Relationship**
General control functionalities	The control environment should obtain functionalities that achieve the monitoring, measurement & assessment of processes, corrective & preventive actions, and communicating/reporting orders or issues to representative stakeholders. • Planning & Routing functionalities: should supervise the balance between supply and demand, the procurement process and its in • and outbound logistics needs. • Decision-making functionalities: should supervise and advise on efficient and effective decisions that boost circular processes. • Forecast, auditing & reporting: shoul allow for information storing and audit the flow of production, simultaneously forecasting potential scenarios for the project outcome.	• The building cases agreed with the functionalities that theory identifies. • Additions were made in terms of the ability to be easily accessible through filtering possibilities for confidential data. Thus, also enabling the information hub functionality. • Some cases also mentioned the need for regular updates to be made, when changes occur within the project.	The theoretical functionalities were approved and strengthened by the addition of the information hub functionality.
Control facilitator across supply chains	• A hybrid control approach, facilitated by an independent party is needed, where centralised and decentralised control merge together. • A centralised control has the potential to improve the joint performance through knowledge transferring and a systematic feedback provision. • A decentralised control based on autonomous links in the chain that collaborate on the basis of link-to-link message passing.	• Different views where gathered in which type control and who should be the main facilitator. • The majority identified the municipality as a potential facilitator due to their impartial position in the chain. • Others, also suggested the control to be through an interconnected software environment, i.e control centres. However, this will require trust, collaboration and a strong integration of all parties, which at the moment is lacking.	A hybrid control where both centralised and decentralised characteristics are merged and facilitated by an independent party, may ease the power interests within the supply chain and allow stakeholders to focus on the achievement of a circular project process.
Circular building tools	• The control environment consists of specific circular building tools, which could facilitate the creation of circular supply chains. • Most of the tools and certifications require time, trust and transparency for their issuing. • Material passports or certifications should be issued by independent parties.	• The majority of cases identified the lack of collaboration, connectivity or shared language for the current circular tools. • In most cases the issuing of material passports in the end of the building project are recognised as important. However, this is still hindered as there is little transparency within the manufacturing processes. • A few cases utilised some tools, which mainly acted as reassurance that the company was undertaking proper circular activities. • Material passports were thought to be best issued by the manufacturers and contractor themselves, while the certification of material performance should be done by a new role in the project process.	Smart technologies implemented with circular practices positively affect environmental and economic performance of circular supply chains.
Social environment			
Regulatory, financial and cultural	• The establishment of a regulatory and financial framework, which contributes to the change of the cultural mindset of the society and organisation involved in supply chains. • A regulatory environment with clear guidelines will create responsibility on all involved stakeholders and facilitate the linear processes towards circular ones. • The absence of short-term profits, which a circular economy currently lacks, is interpreted by companies as higher costs. This hindrances the initiative of companies towards circular building. • A collective cultural mindset towards the implementation of circularity is necessary to align the whole supply chain processes. This also nurtures long-term relationships within companies.	• The relatively weak regulatory environment hindrances the creation of entire circular supply chain, due to several involved companies do not have the urgency to change their processes and operations. • Circular building is significantly more expensive than the traditional projects, this results in a big number of companies not changing towards a circular way of working. Thus, more companies comply to this situation, in order to maintain competitive advantage in the market. • Besides a number companies the cultural mindset is still highly traditional, also as a result of the regulatory and financial aspects. There is a lack of urgency to change their way of working and producing.	A balanced approach, where a clear and strict regulatory environment, which also provides some financial support powers companies to change their cultural mindset by becoming responsible and taking initiatives towards circular building.

As seen from the table above, several relationships were identified when confronting the theory with practice. It is observed that theoretical basis was confirmed in most of the cases from practice, and sometimes additions were made to the variables of the analytical framework. The building cases provided examples on how some components from theory could be implemented and applied in real-life practice. These were aspects that had not been found in theory and add as additional aspects that could be later further investigated. The confrontation acts as input for the Modular Circular Supply Model (MCSCM) in the following sections.

7-2 Introduction to the Modular Circular Supply Chain Model

Modelling techniques are generally used to abstractly represent a complex process or entity in a simplified way (Márquez, 2010). Usually these models consist of several modules or features related to the problem at hand. Therefore, it is crucial to have a clear understanding of the problem in order to appropriately address it in a model. According to Márquez (2010), models fall within different categories, depending on their features. For example, a linear model is a mathematical model composed by a set of variables and operator which are linearly dependent with each other. If there is no dependency noticed, then the model is considered as non-linear. Another category of modelling is the deterministic one, in which a set of variables is determined based on the parameters of the model. In addition, Márquez (2010) states that a model that addresses system changes through time, may have several representation ways, which makes the model dynamic. When dealing with supply chain modelling and especially circular supply chains, the element of time is crucial. Therefore, modelling for supply chains can be considered as dynamic and complex. The complexity within supply chain increases due to the high need of a collaborative environment between supply chain stakeholders, whilst allowing a high level of responsiveness and flexibility (Elbattah & Molloy, 2014). Furthermore, circular principles and their implementation in these supply chains aid to the complexity as it requires alternations in the process phases and potentially introduction of new stakeholders.

The proposed model is fundamentally based on a graph-based approach. This type of modelling enables the representation of complexity into respective modules, while providing flexibility for the modelling environment. These models are flexible, because it consists of modules which can be adjusted based on the specific requirements of different stakeholders and its project environment. Thus, the graph-based approach can be used as a powerful visual and analytic technique for representing complex systems, such as the circular construction supply chain. There are several modelling levels related to graph-based modelling. In this thesis only three levels will be addressed, making the levels of analysis of MCSCM: (i) process, (ii) product and (iii) organisation.

Operationalisation into levels of analysis

Process modelling represents either the static and dynamic activities that occur within an organisation (Law, Kelton, & Kelton, 2000). According to Papadonikolaki et al. (2015), a static model only shows the system structure, which does not change throughout time, such as the BPM Notation. On the other hand, dynamic models take into account the time element, which results in state changes of a system. Within supply chain modelling there is no standard confirmed methodological framework for the representation of a process model. In addition, product modelling takes a closer look at the data specifications for a certain artefact (Papadonikolaki et al., 2015). This level was established for logically structuring data in regards to these artefacts (Eastman, 1999). Dado et al. (2010) argues that product modelling is also present in the built environment, because there is a high need for defining building systems by using advancements in data management. For example, the Industry Foundation Classes (IFC) models allow interoperability between systems. However, Eastman (1999) states that IFC do not address the time element and lack in interconnecting processes and data. Therefore, smart circular tools and specifically control centres are interesting solutions into this level as it is connected to real time data. Seeing the shortcoming that each of these two levels have they are determined as insufficient representatives of a complex system like the construction supply chains. Consequently, an additional level needs to be taken into consideration: the organisational modelling. These models represent the relations that lay between organisations and usually illustrated as networks of graphs.

7-2-1 Process representation

A well-known established model used to describe supply chain processes is Supply Chain Operations Reference Model (SCOR). The Supply Chain Council (2012) developed the SCOR model, facilitates flexibility between the processes and especially the hierarchical configuration between the processes (Li, Arun, & Lim, 2002). The SCOR model operates based on process metrics and aims to satisfy customer demand by describing activities in six primary management processes: plan, source, make, deliver, return and enable (Elbattah & Molloy, 2014). However, there are some disadvantages identified, such as the lack of detail and content for building robust quantitative models, and the lack of a concrete conceptual model that can be applied to existing business systems (Chatfield, Harrison, & Hayya, 2004; Qiao & Riddick, 2004). Therefore, the process modelling will make use of the SCOR-driven process to define additional modules representing the supply chain process phases.

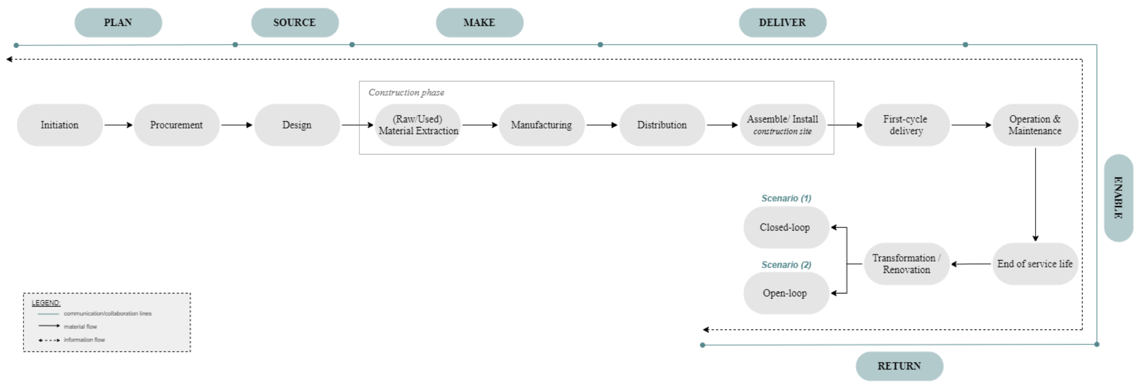

Figure 7-1: Process level of the MCSC model

As seen in Figure 7-1, the SCOR processes are broken down to the project phases starting with **the initiation phase**. Based on the empirical findings (Chapter 6), the initiation process provides important decision-making moments specifically for the alignment of the client and investor towards implementation of circularity. According to den Heijer & van der Voordt (2004), holds the main decision-making moment on whether a new-building is constructed or not. Therefore, in order to facilitate the start of a circular project the decision of either transforming the existing building or new built should be taken. In both cases circular applications aspects need to be implemented, see Table 7-2. It should be noted that the application aspects is not an exhaustive and fixed list, but should rather be seen as recommendations.

The procurement phase heavily depends on the type of the contractual agreements that the projects have. There are contractual collaborations that requests the procurement to happen after the initiation phase, such the case of DBFMO contract. However, there are also other contracts, like the traditional one that may require two moments of procurement (for the designer and contractor). The selection of the contractual agreements depends on the type of project and the client preferences.

The design phase obtains all activities that are related to delivering the design of the new-built project or the transformation project. Traditionally, the design undergoes three processes the sketching, preliminary and definite design. This phase is a critical moment in the implementation of circularity, as it can enable different design strategies. According to the empirical findings, 'design for disassembly' is considered as a significant circular application method for this phase. Designing for disassembly means that buildings are anticipated to be deconstructed in components, which enable reverse loops for re-purposing possible. This would also facilitate the ability to design for product standardisation. Within this method further strategies can be taken, such as designing with renewable, reused, or secondary materials. In addition, it was also mentioned that the design phase should also take into account the aspects of adaptability and flexibility. Thus, allowing for buildings to change their function without the need of major transformation requirements.

The construction phase consists of two SCOR processes: making and distributing. Making refers to all the processes that outline the extraction of materials that undergo specific manufacturing processes into final products supplying various projects. In this phase there are important decision-making moments on the types of materials used in the project. In addition, the production processes can be coordinated in such a way that building components are provided as a service. A concrete example of this was given from the supplier case. An infill product was supplied in such a way that allowed for accountability agreements to be made with the original manufacturers. The infill component is leased to the building owner or a buy-back agreement is established between supplier and building owner. In both cases the infill building component is retrieved once its service life ended.

The distribution refers to all the logistics transportation of these building products to the allocated construction sites, which then follow the assembling procedure. Optimisation of the logistical routes is of high importance. The dismantler case gave the example of organising both forward and reverse logistics routes simultaneously.

First-cycle delivery phase happens specifically when dealing with new built projects. This is the first delivery moment of the building once it has been constructed for the first time. From the empirical findings it was emphasised by several stakeholders that there is a distinction between transformation and new-built projects. Therefore, this distinction is also included into the MCSC model. The distinction between the two types of projects will be further discussed in the organisational representation. During this phase the construction phase has finished and quality checks/inspections happen from clients. This is done to verify whether the building performs and complies to all the requirements set in the initiation phase. From the empirical findings it was often addressed that material passport

Table 7-2: Circular application aspects across different building life-cycle phases

Life-cycle phase		**Circular application aspect**[1]
Plan	Initiation	Decision of new-built or transforming existing building Alignment of client and investors towards circular strategies
	Design	Design for disassembly Design for adaptability and flexibility Design with specified innovative, recycled or reclaimed materials Design for product standardisation
Source	Procurement	Tender processes that include circular criteria
		Selection of companies that have experience with circular building or have interest in getting experience
Make	Material extraction	Conscious choices of types of materials used Use of secondary materials in processes Procurement of materials that can be returned in the process(reused, re-manufactured or recycled)
	Manufacturing	Standardisation of production systems Supply of building components as services Material recovery schemes (lease or buy-back agreements) Draw up of material technical details in a material passport Re-purposing of returned materials and products
Deliver	Distribution	Organisation of regular and reverse logistic distributions
		Optimisation of logistics distributions
	Assemble/Install	Off-site construction and assembly of products on site.
		Delivery of material passports to building owner
	First-cycle delivery	Quality checks of the delivered project
Enable	Operation & Maintenance	Preventive and reactive maintanance to extend life-cycle of building components Update of material passports in case of changes
	End of service life	Draw up transformation or renovation plans
Return	Transformation / Renovation	Involvement of dismantling companies and other relative stakeholders
		Retrieval of material passports and delivery to appropriate stakeholders
		Analysis of the existing building and estimation of components to be reused, re-manufactured or recycled. Deconstruction of building products
		Selective demolition
		Collection of building components to be re-purposed and waste to be disposed
		Delivery of collected in temporary storage locations
		Returns of products and components for reuse purposes to original manufacturers or other parties

[1] The circular application aspects are developed based on literature and the empirical findings.

of the building should be delivered within this phase. Proper documentation of the building material passports is crucial for the enabling of the reverse loops to happen. Most of the cases argued that the responsibility to hold onto this material passport and update if necessary would lie with the building owner.

During the **Operation & Maintenance phase** the first life-cycle operation and maintenance of the building project happens. Maintenance can happen both from a preventive and reactive approach. The preventive maintenance relates to the building components of a building undergoing regular checks to guarantee their current performance. On the other hand, reactive maintenance occurs when the components fail to perform their expected functions. These approaches aid to the service-life extension of the building components and increasing the likeability to be returned into other life-cycles. The material passports are important to be updated during these moments, in order to document the changes and state of materials, especially for the certification of re-purpose possibilities.

Initiation of reverse cycle phase; In comparison to the traditional building process and based on the framework derived from the literature review some additional aspects should be introduced and included for the establishment of a circular process. This entails the reverse loops in which building components are deconstructed in such a way that allows them to be returned and reused in other life-cycles. There are two scenarios for reverse loops: (i) open loop and (ii) closed loop, see Figure 7-2 and 7-3.

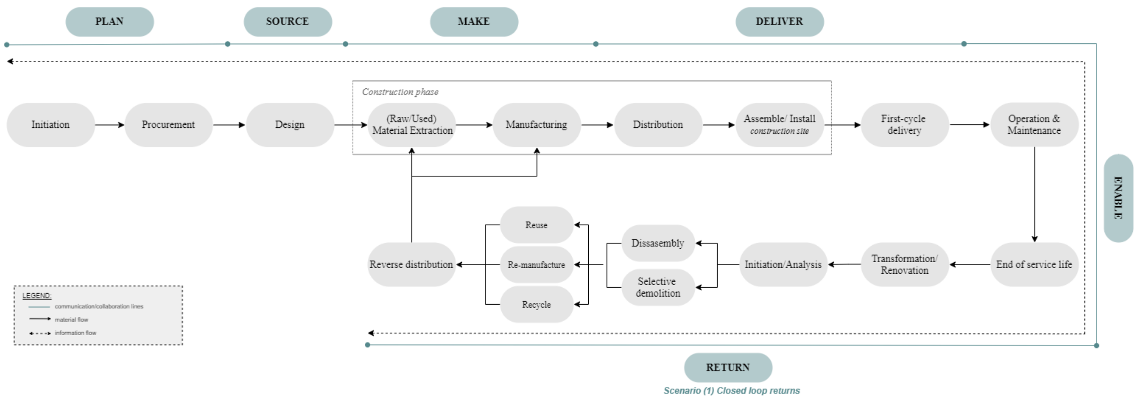

Figure 7-2: Scenario 1: closed loop return of the MCSC model

In both scenarios the reverse loop starts with an initiation moment within which an analysis is conducted on the current condition of the building. Currently, this is a critical moment due to the existing built environment lacking material passports. Thus, the analysis as observed from the developers and dismantler cases should start with a big team of engineers and experts that manually confront the drawings to the current situation of the building. Next, important decision-moments in both scenarios are the potential estimations of the possible deconstruction in building components or demolishing of components that cannot be disassembled. Often demolition happens more often in current projects, due to not being constructed with this intention or due to deterioration of the components throughout time. Within the disassembly additional decisions need to be made on whether the components can be reused, re-manufactured or recycled. These can be direct reuses for certain materials, the dismantler case identifies here materials like ventilation ducts. However, there are also often products and materials that need to be re-manufactured in order to be re-purposed,

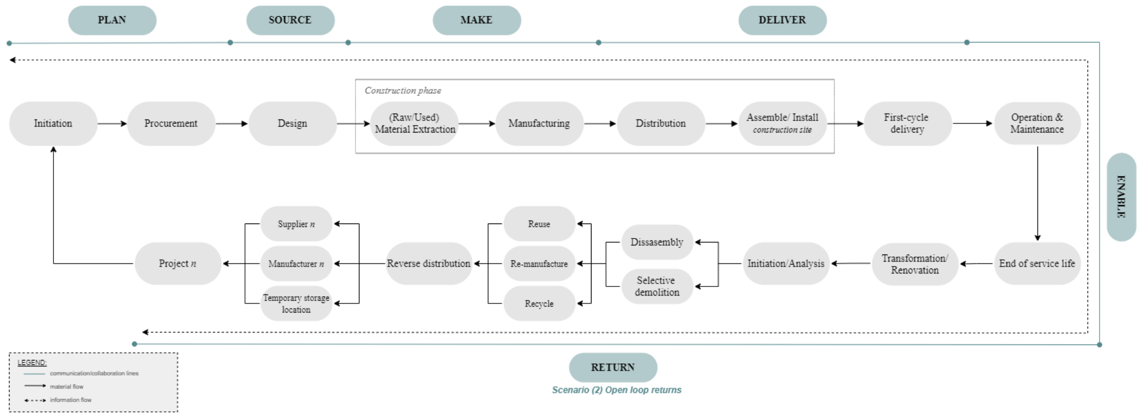

Figure 7-3: Scenario 2: open loop return of the MCSC model

such as the case of concrete blocks. Lastly, materials/products could also follow recycling routes.

Once the re-purposing abilities are estimated then logistical routes can be defined. As mentioned previously these can either be closed or open. In closed loop the building components are returned to the original suppliers and manufacturers, while in open loops they are sold to third part suppliers and manufacturers or stored in temporary storage, also known as circular hubs. In the case of the contractor these storage would temporarily store the materials coming out of a building project and re-utilise them in another project handled by the company itself. Thus, the components could also circulate internally to other projects that a company has. Another example of the operation of storage was provided by the case of the dismantler, who had integrated a workshop in which the recovered materials would get re-manufactured, certified and listed into their online web-shop to be later purchased by external parties located around Netherlands. Th closed and open loop scenarios should not be seen as two separate approaches, but rather as two possibilities on the circulation of materials, that could both happen in a project. Therefore, in the following levels they will be cosidered together, rather than separately.

7-2-2 Organisational representation

The processes that were introduced in the previous chapter are not possible without the collaboration between the different stakeholders. In Section 4-3, an extensive stakeholder analysis was provided. The output of the analysis identified a list of traditional stakeholders, which are regularly involved in building projects. In addition, a list of circular specific stakeholders were identified, as additional stakeholders beside the traditional ones. Theory claims that these are new roles that should be introduced into the process to facilitate a circular building process. However, based on the empirical findings it was observed that traditional stakeholders expand their role to circular specific activities. Theory identified the transformation agent as a leading role towards the initiation of circular buildings especially for transformation projects. Simultaneously, the municipality case put emphasis on the importance for more initiatives to be taken within the existing built environment by developers or other companies. The developer case was observed to have included this role in addition to their traditional operations. Furthermore, it was observed that the traditional demolishing companies can alter their processes by selective demolishing and analysing dismantling possibilities for the building projects. The dismantler case is an example of this adoption of operations. Furthermore, logistical parties can include also reverse logistics of the recovered materials by optimising their route planning, with the help of technologies. However, there are still some circular specific stakeholders that could potentially be introduced into the Although this chapter introduces them as potential stakeholders, the activities within this organisations could potentially be facilitated by circular building tools. In the following section, it will identified if any of the current tool obtain qualities to overtake these roles. Figure 7-4 visualised the new stakeholder environment for the MCSC model.

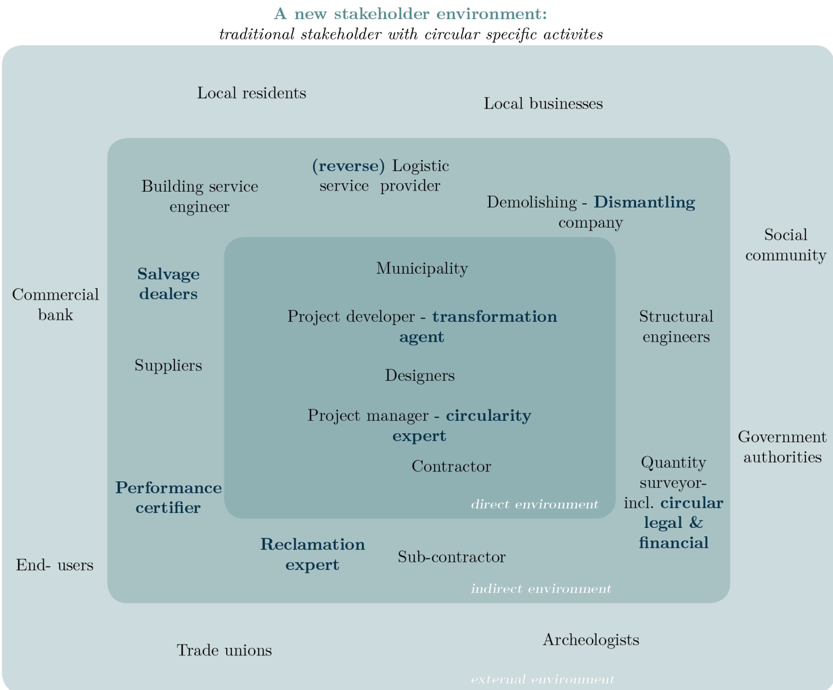

Figure 7-4: A new stakeholder environment for the MCSC model

The organisation networks often start with interactions between the client (municipality or project developer), project managers and investors to study the possibilities and provide a set of requirements and wishes towards the project. This is the moment where either an external circular expert or the project manager could undertake this role to advise on the possibilities over circularity implementations. In the procurement phase this can be further elaborated by also being enforced by the 'quantity surveyor' by analysing legal and financial opportunities towards circular building actions.

Traditionally, the design phase only includes the interactions between the designer and different engineers who assist the drawings by including technical specifications. This also depends on the contractual agreements as sometimes in this phase sometimes contractors can also be involved. Both theoretical and empirical findings often emphasised the importance of having a more integrated approach. Therefore, the MCSC model proposes, besides the traditional collaborations, to especially involve suppliers into the design phases as they have an overview on their inventory and could simultaneously help in developing standard building components as services. In addition, circular experts can also be important in this phase at first, to advise on the types of processes. However, this role is expected to eventually disappear once more companies obtain experience with a circular building process.

For the reverse loops to be established actors like the building owner and end-users are thought to be crucial. The end-users act as information input to the building owner in building components failing to highly perform. Furthermore, the building owner is expected to hold onto the material passport of the building and have it updated during maintenance moments. By having a well-established collaboration in the operation & maintenance phase, then the initiation of transformation or renovation project can be established. In these processes the demo/dismantler stakeholder is considered of high importance. They will be in charge of coordinating processes for the dismantling or selective demolition of the building. Within these processes stakeholders like salvage dealers, performance certifier can be involved to evaluate and guarantee the possible re-purposing abilities of the recovered components. These can be then retrieved by logistical service providers who distribute them in two scenarios. First scenario includes the distribution to the original suppliers and manufacturers, while the second scenario is the distribution to third party suppliers, manufacturers or in temporary storage. The dismantler case showed that often the logistical routes are internally facilitate by partnering with logistical service providers and that these return loop scenarios could be intertwined.

The MCSC organisation model represents and suggests possibilities of a more integrated approach towards a circular supply chain and also provided the introduction of some potential new stakeholders in some phases. As seen In the following section the product is discussed to identify the data information that the MCSC model needs for its functioning.

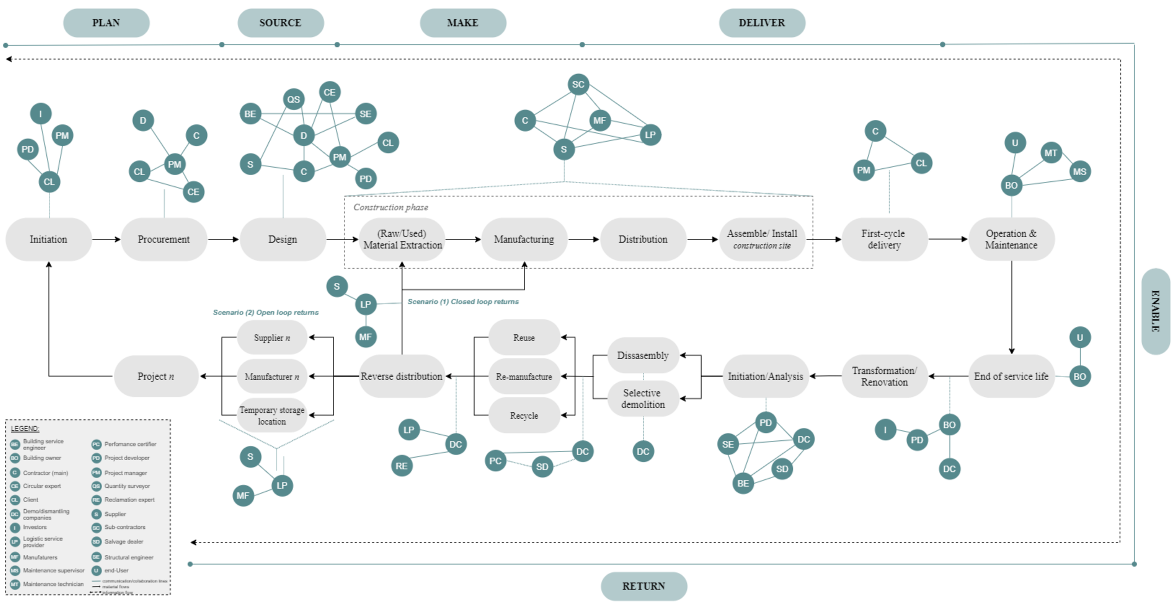

Figure 7-5: The organisational representation for closed loop scenario of the MCSC model

7-2-3 Product representation: information control environment

The product level refers to the control environment that supports all the process phases and interrelationships between stakeholders. The control environment represents the data information, which is exchanged between different stakeholders, together with the tools and ICT systems that support this exchange. Overall, the control environment for the MCSC model is considered not anymore as one ultimate control centre, but rather a compilation of information systems and tools that allow for data exchange. The control environment is should consider eight main requirements, deriving from theory and empirical:

- Modular structures - are understood as independent modules that can be used and adapted in different specifications of building projects. This is highly important due to stakeholders also having different requirements for their operations.
- Quick connectivity - referring to the ability to connect quickly in existing systems of companies.
- Coordination and collaboration - between the different tools, and the ability to facilitate the coordination of organisation structures. This can be achieved by monitoring the performance of the systems and updating them accordingly.
- Relationship management - relates mainly to the
- Open accessibility to stakeholders within supply chains and to the public - allowing accessibility of certain information by different stakeholders at any time or place.
- Safe and secure environment - this is highly connected to the previous functionality. Most cases emphasised the need to have a filtering possibility where the public and different stakeholders have a certain limit of accessibility to the control environment.
- Provide a common language - mainly related to all tools/systems being aligned to the same set of regulations and have similar alignments in communication of data. Or the the use of a similar list of tools.

Data providing area

The data providing area consists of the information that stakeholders hold and could provide to the control environment. The information was derived through the empirical case interviews. It should be noted that information lists provided in Figure 7-6 are not exhaustive lists, and that more information data may be available. It is observed that each of the stakeholders provides data that is complimentary to the creation of the circular supply chain. Within the building cases also the systems and tools that were used were identified, which supported their operational processes. Interestingly it was observed that the majority of stakeholders made use of at least one circular building tool, mapped in Chapter 5. However, no specific circular tool was observed to be widely accepted by various stakeholders. Each building case emphasised that these tools were mainly to confirm undertaken routes were circular and do not facilitate processes. The main overarching tool

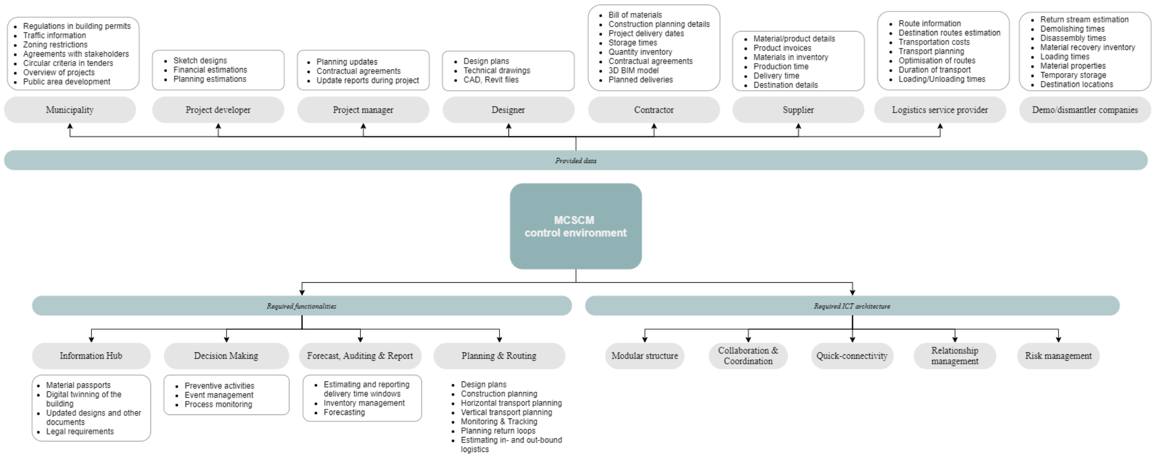

Figure 7-6: The product representation of the MCSC model

is Madaster as a whole platform as it was able to connect with the BIM information system and assisted in creating material passports. In addition, the majority of the cases made use of the information system BIM and had other tools and systems connected around it. Therefore, both BIM and Madaster are observed as systems that have high possibilities to further develop and enable the connectivity functionality with other tools.

Data requiring area

The data requiring area identifies the type of information that is required for the circular supply chain to function. Based on theory, three main functionalities were identified that a control environment should obtain, which are applicable to the general control environment too. First, the 'Planning & Routing' concerns all the material flow movements from one phase to the other. This could be either horizontal or vertical movements, thus within and cross-chain. A very critical data requirement is the construction planning for these movements to happen and become more efficient, within which the logistical in- and out-bounds are provided. Next, the 'Forecast, Auditing & Reporting' should obtain functionalities such as ability to analyse and forecast activities that need to be taken within circular supply chains, like logistical distribution times or time windows for production processes. Third, the 'Decision-Making' functionality has been observed as a crucial one for the overall supply chain management. Here the as the process is being monitored, the control environment should be able to also manage events. These events may be unexpected, which will require quick reactive decision-making moments. Beside reacting to events the control environment should also be able to prevent by smart tools that can forecast deviations or changes in the process. Lastly, based on the empirical findings additional functionality requirements were mapped, which are grouped under the category of 'Information Hub'. The cases recognised the need to produce and share materials per building project, which are updated regularly in instances of maintenance and other changes. Other functionalities are identified within this category, such the storing of design details and regulations, agreements and other contractual collaborations for the ability to track back original suppliers and manufacturers. An overview of the MCSC model including all three levels is provided in Figure 7-7.

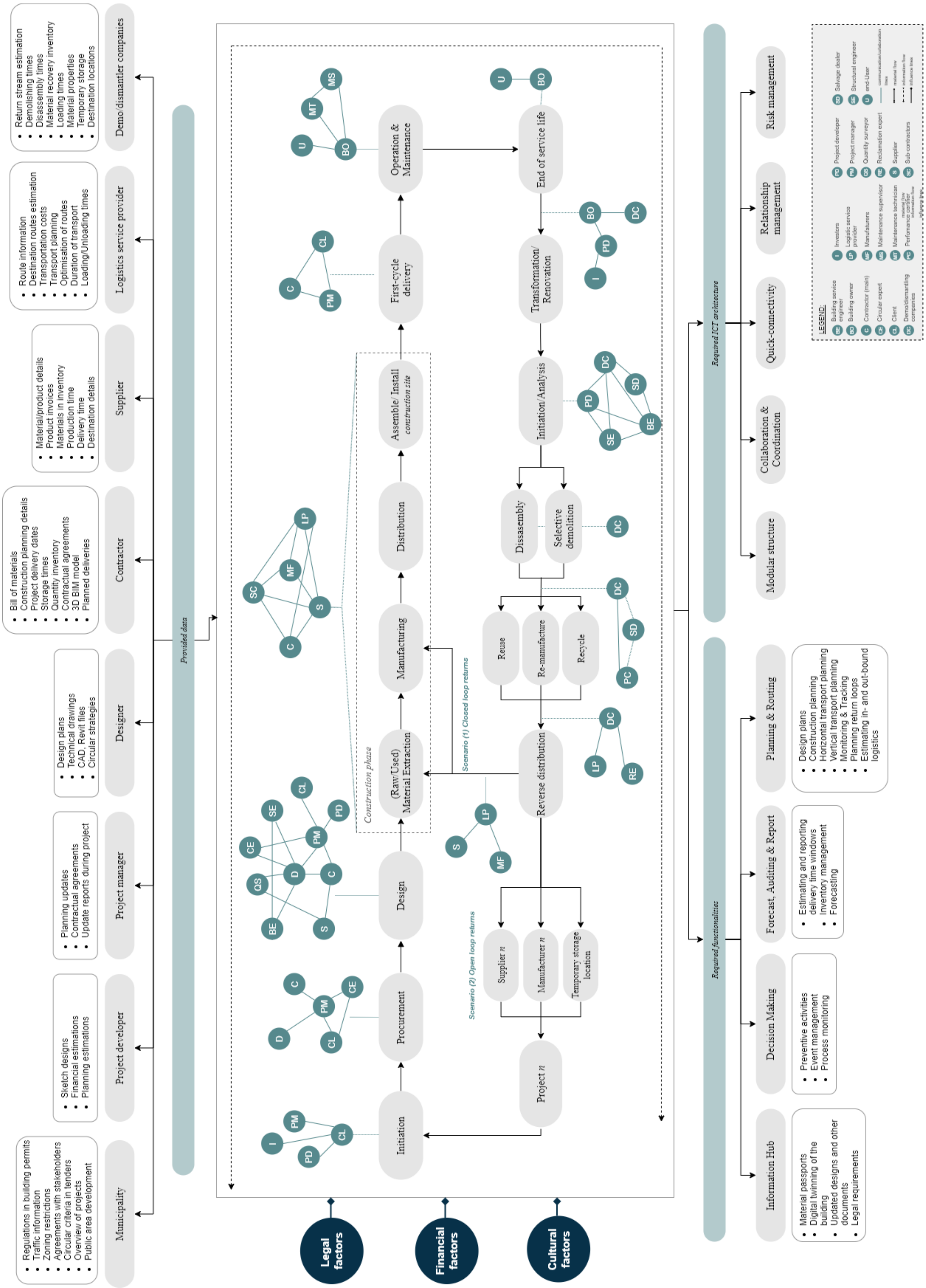

Figure 7-7: The Modular Circular Supply Chain Model (MCSCM)

7-2-4 Social environment factors

Beyond the case itself discussed it there are also three contextual variables that indicate whether a circular supply chain can be achieved. These are the three variables that were identified both from theory and practice as critical for the circular supply chain: legal, financial and cultural. The social environment is seen from both theory and practice inputs as a highly influential environment in the success of the processes of a circular supply chain.

Based on the empirical findings, the *legal dimension* is observed to be lacking. Often the municipalities are not owners of the land, which hinders their influence in decision-making moments. The regulatory environment is yet to be established in a quantitative way, as the ambitions that each municipality has are still being investigated. Currently, legal requirements take into consideration the MileuPrestatie Gebouwen (MPG) calculation which is obligatory per every building permit, and sometimes circular criteria which are included into tendering processes. There are also subsidy possibilities that are provided by the government to aid companies that take initiative towards However, by most cases the current regulations do not commence most companies to take initiative in changing their operation processes towards a circular building process. Thus, the government is required to have a more steering role through stricter or new regulations.

The *financial dimension* is a very critical dimension for the circular supply chain. Most of the companies are still investigating business models that not only implement circular process coordination, but also provides profits in a short term. Currently, the market behaviour is still significantly directed towards choosing the cheapest options. Interestingly, often companies expected for circular processes to be cheaper than linear, but many building project examples have made it clear that this is not the case. However, the interviewed cases of developers, suppliers and dismantlers are examples on how circular approaches can be undertaken, whilst making profit. In the case of the supplier the infill service they provided was investigated and estimated to have a life cycle of 15 years. Thus, the financial strategy included leasing agreements with monthly/yearly payments or selling their product with a buy-back agreement. In addition, the developer case also provided a distinction to the financial requirements between a transformation and new-built projects. Transformation projects usually need a bigger investment since the initiation phases and have unforeseen budgets, which requires to include in financial estimations a higher percentage of uncertainty budget, for example from 5% to 10%. In addition, it was observed that banks also have specific investing requirements depending on their portfolio. If designs are made to transform a building with a flexible and adaptable ability i.e. changing function from office to commercial purpose, the banks are not willing to invest due to the latter function not being included in their investing portfolio.

The *cultural dimension* is tightly related to the current mindset of the stakeholders and their approaches to the project. From the empirical findings it was observed that the market behaviours is significantly still linear. This comes due to several factors, such as companies themselves not wanting to change, because their operations are profitable and due to legally not being required to do so. From the empirical findings it seems that the awareness is increasing and in the last couple of years more companies have recognised the importance of building circular. This creates a chain effect for more companies who want to keep their competitive advantage in the market. However, the 'greenwashing issue' is still present and attention need to be given to it.

7-3 Bringing the MCSC model closer to real-world scenarios

In this section the MCSC model and specifically its modularity is tested through a case test study. The case test is a real life project: The EDGE Olympic building and the MCSC model will be used to portray what processes were included, the organisational representation of the project and its control environment. It will act as a validation of the proposed model and as a starting point for the discussion.

This case study was chosen due to it being undertaken by one of the empirical case representatives. In addition, the case study does not hold all the components that where discussed in the, MCSC model. Therefore, additional literature sources will be used to fill in any gaps. In addition, the social environment variables are revisited to understand the implications that they have in real-world situations.

7-3-1 Case introduction

The Edge Olympic is a project that made use of an existing building originating from the 1990, also known as the 'Olympic Plaza' (de Architekten Cie., 2018). The project was initiated by the developers Edge Technologies formerly known as OVG Real Estate, who aimed to exploit the existing building (jansen, 2018). The Edge Olympic aimed at minimising environmental impact. Instead of demolishing the original building, a redevelopment was chosen; materials were reused and circular products and systems were introduced (Vos, 2018). The building underwent a renovation and extension of two additional floors over the existing structure. This required for processes and organisation structures to be revised and oversee risks accompanied to renovation projects.

Figure 7-8: EDGE Olympic project (retrieved from Edge Technologies)

The project was delivered in 2018 as a flexible office building and co-working spaces, acting as the headquarters of the client, but also leased to different companies, among others Ebbinge, Epicenter, EVBox, Software Improvement Group (SIG), The Media Nanny, DFFRNT Media, and Singularity University Holland (van Leeuwen, 2018). In addition, the office building was designed with the ambition to merge smart technologies, well-being and circularity. The project received several certifications (Well Platinum certification, BREAAM Excellent and Cradle2Cradle) due to its significant performance as a smart and healthy building and increasing well-being to its tenants (vanEesteren, 2019).

7-3-2 Confrontation to the proposed MCSC model

The confrontation of the case to the MCSC model will be done based on the three operational levels; process, organisation and product. The MCSC model diagrams will be adapted to the case and the modules that are not addressed will be highlighted.

Process level

The Edge Olympic project was initiated with the ambition to implement strategies that had minimal impact on the environment and maximised the well-being of the people. As mentioned before, the Edge Olympic emerged from the existing office building dating from the 1990s. Therefore, the building process starts with second part of the MCSC model (Figure 7-9), where the service life of the 90s building ends and an analysis is done by dismantler Beelen B.V. for the deconstruction possibilities of the building. From the analysis it is concluded that the concrete structure can be largely directly reused, while the other building layers (skin, service and space plan) were either dismantled (roughly 2880 ton of materials) or selectively demolished. According to Beelen (n.d), during the project time up-cycling processes were not well established for the existing building, which concluded in roughly 97.8% of the deconstructed materials to be recycled and the remaining to be incinerated. The only up-cycling moment in Edge Olympic is the recycling of roughly 10% of the skin layer materials into the flooring, i.e. the old natural stone now serving as a floor in the ground floor (Vos, 2018). This constitutes the circular strategies that 'narrow' resource flows and maximise material efficiency.

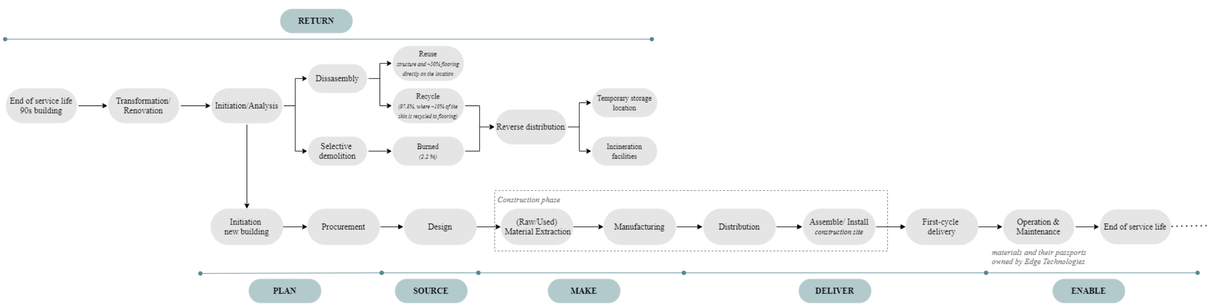

Figure 7-9: EDGE Olympic indication on process level

Figure 7-10: EDGE Olympic facade construction (retrieved from van Eesteren, 2021)

Besides strategies regarding the skin and structure of the building, also strategies for the infill of the building were undertaken with sustainable principles in mind (Table 7-3). The interior designer of the project (Fokkema & Partners and Concrete Architects) brought also these principles by designing furniture and other materials that met the VOC (volatile organic compound) emission requirements of WELL certification.

Figure 7-11: EDGE Olympic structure construction (retrieved from van Eesteren, 2021)

Table 7-3: Circular applications of the Edge Olympic project

Life cycle phase		Circular application	Building layers
Plan	Initiation	Decision to transform existing building and addition of two new built floors.	Structure
	Design	Design for disassembly for the new added floors	Structure
		Design with recycled and reused materials from the existing building	Skin, Structure, Services, Space plan, Stuff
Source	Procurement	Collaboration with parties from past relationships	-
		Inclusion of companies and circular advisers	-

Table 7-3 continued from previous page

Life cycle phase		Circular application	Building layers
Make	Material extraction	Choosing for reuse and recycle of the natural stone present in the existing building	Structure
	Manufacturing	(Downcycling) Recycling of the existing materials from the old building and incineration of the other ones.	Skin, Services, Space plan
		(Upcycling) Recycling 10% of the skin in the new flooring	Skin, Structure
		(Upcycling) Producing materials and products for the new additions with the ability to be dismantled.	Skin, Structure
Deliver	Distribution	Logistical distributions of secondary materials were organised by the dismantlers.	-
	Assemble/Install	De Groot Vroomshoop Glued Timber Constructions supplies and installs the laminated timber construction, floor and roof elements and timber frame wall elements	Structure, Skin, Space plan
	First-cycle delivery	Delivery of material passports to Edge Technologies	-
Enable	Operation & Maintenance	Preventive and reactive maintenance to extend life cycle of building components through digital infrastructure	Skin, Space plan, Services, Stuff
		Update of material passports from Edge Technologies	-
Return	Transformation/ Renovation	Transformation of the 1990 Olympic Plaza building	All
		Selective demolition and dismantling of other building components.	Structure, Skin, Services
		Reuse/recycling of collected materials on site	Skin, structure

Strategies aligned to slowing-down the deterioration of the materials were also undertaken. These strategies aimed at maintaining the repairing any defects happening around the building during the operational phase. For this purpose an infrastructure of smart interconnected technologies was created, in order to map the quality and well-being of the spaces (temperature, light, noise, occupancy and other qualities). All these strategies allowed to keep a low carbon footprint, while still maintaining the materials in adequate shape for potential re-purposing in other life cycles.

In order to close resource loops, the demountable and cradle-to cradle design and construction strategy was chosen for the new additions of the building, particularly the facade (EDGE Technologies, n.d). This decision was undertaken between client and designer, which were also advised by a couple of advisers. In addition, material passports were generated and placed under ownership of the client Edge Technologies. This material passport assisted during the process of the building as a communication medium for the stakeholders and enable the reuse and recycling of the existing building.

Organisation level

The organisational structure is unique for the Edge Olympic, as the client; Edge Technologies was not only the developer but also the building owner and responsible for the operational phase (EDGE Technologies, n.d). Therefore, the client received a central role in the organisational structure, since they steered the development perspective and the management & maintenance functions (EDGE Technologies, n.d). There are additional stakeholders that make up the project team for Edge Olympic. An overview on the project details and stakeholders have been provided in Figure 7-12.

The stakeholder environment consists of several actors besides the client, such as designer, contractor and advisers that have influence in the development of the project. In the case of Edge Olympic it is observed that several circular specific actors are also included, such as the reclamation experts and circularity expert who assisted in the appropriate circular strategies

Project Information | EDGE Olympic

Location | Amsterdam
Project start | 2016
Project delivery | 2018
Bruto surface | 12.500 m2
Program | O ice builing

Stakeholders

Client | EDGE Technologies
Building management | EDGE Technologies
Architect | de Architekten Cie.
Contractor | JP van Eesteren
Interior architect | Concrete Architects & Fokkema en Partners
Landscape architect | de Architekten Cie. & Municipality of Amsterdam
Construction advisor | Bartels groep
Installation advisor | Deerns
Acoustics advisor | DGMR, Den Haag
Building physics advisor | DGMR, Den Haag
Fire safety advisor | DGMR, Den Haag
Dismantlers | Beelen B.V.

Figure 7-12: EDGE Olympic project details

to be implemented. In addition, two traditional actors adopt also circular roles, like Beelen acting as a dismantler and the client as a transformation agent.

According to van Eesteren (2019), the client had past collaborations with some of the stakeholders, which contributed to some peculiarities deriving from the temporary nature that characterises the supply chain to be avoided. In addition, past collaborations contribute to the creation of long-term relationships, which create trust and higher information exchange between different stakeholders (Winch, 2010; Vrijhoef & Koskela, 2005). Furthermore, collaborations between the different stakeholders depended on the project phases of Edge Olympic (Figure 7-14). An intensive collaboration between the dismantler, client, designer, circularity expert and contractor was present in the beginning. As the project progressed other close relationships occurred when the new-built floors processes were initiated. Within this part of the process advisers, client, reclamation experts and other traditional stakeholders collaborated tightly with each other, where information was mainly coordinated by the client or designer (EDGE Technologies, n.d, 2021; Gerding,

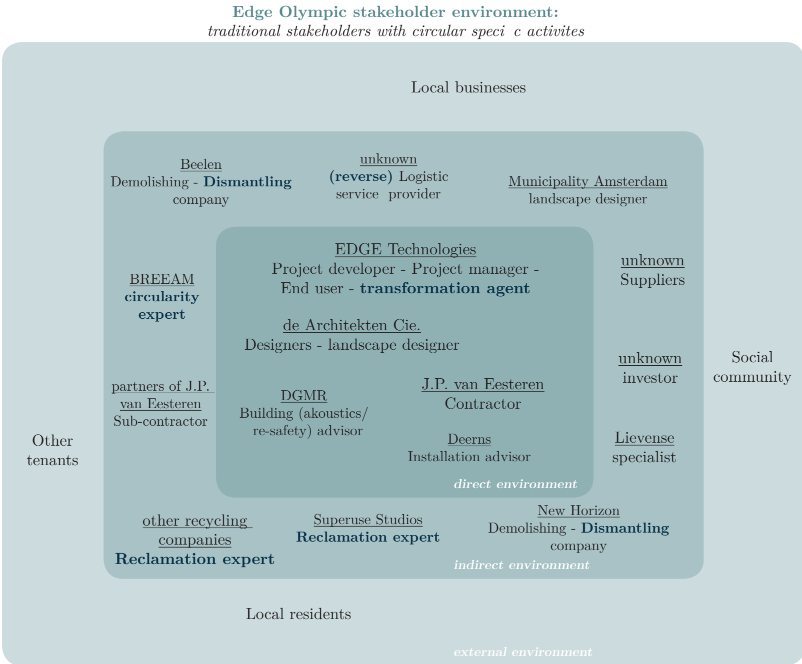

Figure 7-13: EDGE Olympic stakeholder environment

Wamelink, & Leclercq, 2020).

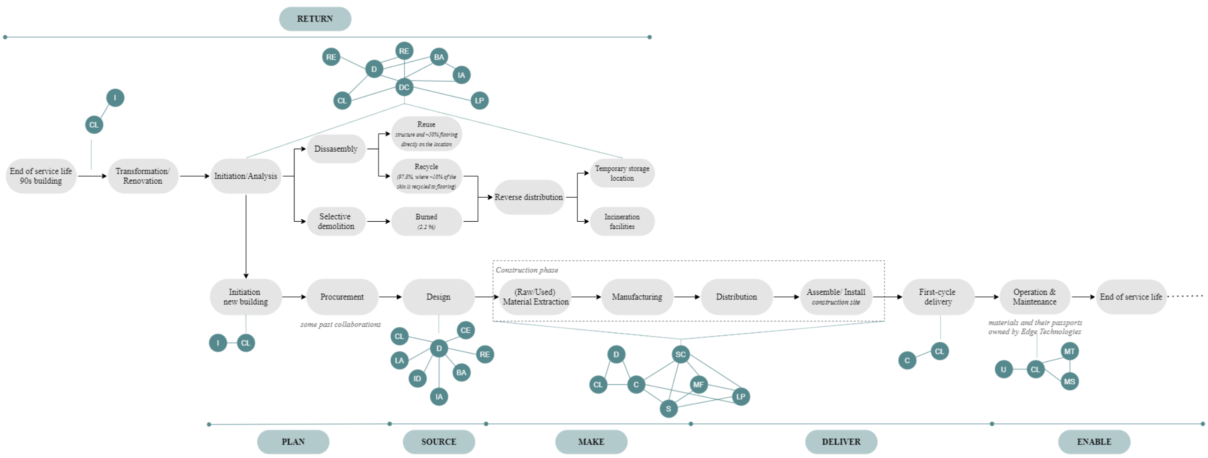

Figure 7-14: EDGE Olympic indication on organisation level

Product level - control environment

The control environment of the Edge Olympic case during the development of the project made use of BREAAM, an established assessment method of sustainability for building projects (vanEesteren, 2019). This assessment method assisted in the decision-making moments, and acted as circularity expert. Thus, this case shows that the circular-specific roles introduced by theory as new roles in the process, could be undertaken by tools and technologies too. In addition, a material passport of the building was issued and owned by the client Edge Technologies, to help facilitate information exchange between different stakeholders. Ultimately, the material passport had the aim to facilitate reverse loops once the building reached its end-service life. For the Edge Olympic case no other documentation was found about the specific circular building tools used during the different processes. However, the use of BREEAM and material passports, were able to facilitate the creation of a healthy and circular building. This is noticed due to the Well Platinum certification that the project received for its positive impact on well-being and environment (EDGE Technologies, 2021).

However, the control environment continued to be developed and used throughout the operational & maintenance phase. The building makes use of a digital infrastructure with the help of smart technologies (Vos, 2018). This infrastructure consists of inter-connected technologies that control and gather data on occupancy of rooms, lighting, temperature, noise and air quality of the building (Vos, 2018). The information gathered within a single cloud platform is accessible by the managers of the building (Oudot, 2019). However, some of the information is also visible to the tenants and users of the building, through a mobile application. This sharing of information provides to tenants the ability to adjust elements like temperature or lightning based on their specific needs. These change requirements are gathered and analysed in the central control environment of the infrastructure. Overall, this control environment during the operational phase provides insights into the status of the building and can enable adaptive maintenance(Oudot, 2019). Following the sustainability ambition and creating such control environment resulted in the Edge Olympic to optimise its energy usage, and further minimise the impact in the surrounding environment (EDGE Technologies, n.d). By having a well-documented operational & maintenance history, ultimately enables for appropriate return streams of materials and products to happen, once the end-service life of the building is reached.

7-3-3 Social environment factors

The legal collaboration between the stakeholders in the Edge Olympic followed a traditional contractual agreement, where the main decisions were held from the client and designer (Gerding et al., 2020). The collaboration with the municipality of Amsterdam was only in lines of the landscape. In addition, due to the ambition of the municipality becoming more energy neutral the Edge Olympic approach towards becoming more energy efficient building was supported and indirectly aided to the fulfilment of this ambition.

The ambitions and approach to include circular principles in the Edge Olympic, required that the project had extra financial investments in the beginning of the project. This was achieved due to the client being willing to establish a circular building where energy and material efficiencies are maximised. According to Edge Technologies (n.d), the investments were supported by also investors and tenants due to the space and building quality that would be delivered. In addition, due to the smart technologies within the building returns on these investments were calculated and expected. During the processes also smart financial decisions were made that did not cost additional costs. For instance, the reuse of the granite facade panels, had minimal costs due to it being present on site of the existing building. Dismantling it from the old facade, re-sizing, and re-laying was in the end cheaper than buying new natural stone tiles and having them installed. (EDGE Technologies, 2021).

The Edge Olympic succeeded in addressing and implementing circular principles due to the cultural mindset of the client and designer already in line with circular building. Furthermore, appropriate stakeholders were involved such as dismantlers, circular experts or reclamation experts that supported these goals and directed the project towards its outcome.

7-4 Reflection on key aspects of this chapter

The chapter started by first confronting theory to empirical findings, to disntinguish relationships and help implement both findings into one merged model. Then the proposed model: Modular Circular Supply Chain Model was introduced. The description of the model consisted of three levels: process, organisation and product. Within each level different modules were discussed and introduced. For example, the process level introduced the new process phases modules that create a reverse loop in two scenarios; open and closed scenario. In addition, the organisation level introduces the stakeholder modules, their interrelationships and their phase of activity. The product level provided modules for the data requiring and providing areas for the control environment. It should be noted that these modules should be considered as recommendations and that adjustments can be made to them, new modules can be added or the current modules can be removed depending per building project specifics. Furthermore, the MCSC model suggests that the control environment should not be considered as one physical control tower, but rather as an interactive environment between different information systems and circular building tools. More research on the technical possibilities is needed, to estimate whether all these tools and systems can be integrated into one information system like a control centre. To bring closer to the real-world implementation a test case, Edge Olympic, was investigated. Here the MCSC model was adapted based on the project specifics validating the modularity aspect of the proposed model.

Chapter 8

Discussion & Conclusion

This chapter will provide the conclusion of the thesis, whereby the theoretical and research questions will be answered. Then, recommendations will be provided in regards to the topic. Lastly, limitations and future research possibilities will be proposed.

8-1 Conclusion

This thesis explored how circular economy principles could be implemented and enhanced within construction supply chains by investigating also its control environment. The thesis's scope was mainly on the process and the respective actors involved in such supply chains. Ultimately, the research aimed to identify different requirements and components that eventually provide an entire representation on circular supply chain. Therefore, the research addressed the following main question: *"How would a circular supply chain environment within the construction industry look like based on theoretical and practice inputs?"*. For this question to be answered several sub-questions were formulated, which are answered below.

Theoretical sub-questions

1| What is the nature of the current building supply chains and their management in current theory?

The first theoretical sub-question revealed several peculiarities present in the construction supply chain context, where among others the fragmented nature, competitive environment, temporary organisations and one-of-a-kind production make it difficult for an integrated collaboration in the horizontal and vertical axis. As a consequence the management of supply chains is crucial in order to establish a transparent, trusting and collaborative supply chain environment. Besides collaboration, coordination is another important component of SCM, as it mitigates uncertainty by synchronising information and material flows. These activities can be facilitated by IT functionalities i.e., planning and routing of supply chain, monitoring and information sharing. With the help of these IT facilitators, a supply chain environment with information and communication is available is able to enable a timely, correct and full information about the demand and supply along the value-adding chain. Furthermore, coordination is interlinked with integration. SCM enables integration from an organisational perspective (different supply chain stakeholders collaborating together) and from the managerial perspective (strategic, tactical and operational decision-making levels). Within each of these SCM components, decision-making is an overarching crucial task that happens through the three levels and addresses sourcing, transforming and distributing responsibilities.

2| How is the concept of circular supply chains constituted in current theory?

When addressing the concept of circularity in construction supply chains, the aforementioned peculiarities are increased and complexity is enhanced. This is due to researchers and organisations viewing circular economy in different perspectives that address individual aspects, such as energy, emissions, health, natural resources, and economic systems. However, to create a circular economy environment these aspects need to be jointly taken into consideration. Achieving a circular supply chain would mean the *provision of self-sustaining production systems, where materials are returned to such systems, thus reduction of waste generation and enhancement of the building life-cycle.* The recovery process is a crucial action field into the establishment of circular supply chains. Currently, this was identified to happen at the end-of-life of products/materials, when recycling or down-cycling remains the only solution. Thus, not properly utilising the reverse loops. To prevent this the linear action fields of take, make, distribute and use need to be aligned in such a way that will enable up-cycle recovery loops. For circular supply chains to be successful an integration between production and distribution needs to be established, as it will enable more optimised efficiency within the linear recover action fields and allow recovery loops to be generated. Two types of recovery loops were noted in literature: open and closed. Closed reverse loops are understood as the return materials stream that bring the recovered building materials to their original suppliers and manufacturers. On the other hand, the return streams of open reverse loops where done towards third party suppliers and manufacturers. The second theoretical sub-question made possible to frame the concept of circular supply chains and initiate the analytical framework.

3| What are the main variables that allow the design of circular supply chains environment according to theory?

In order to answer this question different sources of literature were used to synthesise the components that facilitate the creation of a circular supply chain. Four main environments (production, organisation, control and social) were further investigated by means of literature. Each environment identified around three main variables that address aspects within this environment. These variables are required to be investigated in order to identify their needs and ultimately facilitate a circular supply chain. According to the literature review the eleven identified variables consisted of: operation & process coordination, circular reverse loops, strategy integration, internal alignment, cross-chain collaboration, information exchange, smart ICT architecture & functionalities, facilitator of control environment, circular building tools, legal/regulatory factors, financial factors and cultural factors.

The developed analytical model consisted of the joint consideration of the four environments and eleven variables. This framework formed the theoretical basis that would be used and tested through the empirical analysis.

Empirical sub-questions

4| What tools and information systems are present within the building industry, facilitating a circular control environment?

Answering this sub-question has been achieved by means of a desk-study from academic papers and online researching on the various information systems and circular building tools that exist in the current control environment of the building industry. From this desk-study, several information systems were noted, such as ERP and APS focus in coordinating the planning, scheduling and other activities of an organisation/company. Other systems, focus on planning logistical distribution operations, such as TMS systems, or deal with the internal warehouse operations, such as WMS systems. However, a commonality between these systems is the lack of collaboration and coordination across one's company borders. Building Information Modelling (BIM), seemed to be the only system that provides such collaboration possibilities as it provides system packages that encompass different stakeholders of supply chains. However, there are still limitations towards these systems, as they mainly are being applied in specific stages of projects and does not yet cover the entire supply chain. Furthermore, the component of real-time information seems to be the overarching limitation between all the identified systems.

Furthermore, attention was put to the many tools being developed in the last couple years that claim to enable circularity. The continuous research and development of new tools for facilitating the creation of a circular environment, indicates that the current tools and their indicators are not satisfactory for each level of the circular context. Based on the selecting criteria (Chapter 5), 32 different tools were identified, meaning that stakeholders are interested in the development of CE facilitating technologies. During the confrontation of the tools to the analytical model, several inefficiencies were noticed in the majority of the variables. The main result of the analysis showed that the majority of tools are being developed with the same purpose: to measure and give scores on materials/products or organisations on how circular they are or perform. Furthermore, these scores vary per tool, which makes the comparison of results difficult. In addition, the absence of a standard framework of circularity indicators is a hazard in developing an integrated circular supply chain process. Overall, it is observed that the control environment is oversupplied by tools with similar purposes which have unique program languages or measurability. On top of the lack of a common language, the majority of the tools stand-alone and do not connect and collaborate with each other. If there is collaboration then it is noticed that this is mainly done with the Madaster platform and the BIM system. Furthermore, the absence of tools overseeing among other the legal, financial and cultural factors show that a significant number of areas that theory identifies as critical for the creation of CSCs is lacking. This also raises the question of the greenwashing issue; thus, just providing a score or assessment through this tooling, it is not guaranteed that actions are taken and reverse loops are created.

5| How is the MCSC theoretical model perceived by organisations active in the building industry?

To capture the perspectives from the majority of the stakeholders involved in supply chains, it was decided to investigate both the stakeholders within the direct and indirect influence environment, which was established in Chapter 4. Within the same analysis also circular specific stakeholders were identified, which in theory they were considered as new to be introduced stakeholders. The perspectives of stakeholders were considered as building cases. The perspectives were first collected per stakeholder and a individually described. Each description was done on the basis of the analytical model in order to enable comparability of findings. The descriptive sections ended with a tabular visualisation of the main findings of the case at hand. These main findings initiated the within- and cross-case analysis case analysis. Within the cross-case analysis several similarities and differences between the perspectives of stakeholders were identified. The main similarities were mapped in the tendency of the cases to mainly focus on their internal alignment and coordination of processes towards circular building practices. While the main differences were in regards to how the cases approached circular applications in a different way, and this is aligned due to their position and function into supply chains. Ultimately, the empirical findings showed that circular an traditional stakeholder should not be considered as separate roles, as traditional stakeholders can integrate some of the activities of a circular actor.

Answering the main research question

"How would a circular supply chain environment within the construction industry look like based on theoretical and practice inputs?"

Ultimately the main research question identified four main environments of analysis: production (understood as the processes and operations of supply chain), organisation (understood as the stakeholder network structures), control environment (understood as smart tools and technologies that help circularity) and social environment (understood as the cultural, financial and regulatory areas). Each of the environments comprised of additional variables. For the purpose of providing a clear understanding on the topic and answer this question the approach of supply chain modelling was undertaken. Supply chain modelling aids into visualising a complex environment in a simplistic way. The research proposed a Modular Circular Supply Chain Model. The description of the model consisted of three levels: process, organisation and product. Within each level different modules were discussed and introduced, which had been derived from the confrontation of theory with the empirical findings. The process level introduced the new process phases modules that create a reverse loop in two scenarios; open and closed scenario. In addition, adjustments and new considerations of the traditional phases were also provided, such as the delivery phase being addressed as 'first-cycle delivery', emphasising that there could be more than just one life cycle delivery. The organisation level introduced the stakeholder modules, their interrelationships and their phase of activity. The product level provided modules for the data requiring and providing areas for the circular control environment. It should be noted that these modules should be considered as recommendations and that adjustments can be made to them, new modules can be added or the current modules can be removed depending per building project specifics. Furthermore, the MCSC model suggests that the control environment should not be considered as one physical control tower, but rather as an interactive environment between different information systems and circular building tools.

8-2 Recommendations

The thesis identified the complex environment that a circular building supply chain has, together with several components as critical for the development of such environment. The MCSC model included all variables in the attempt to introduce a general image of a circular supply chain environment by making this concept more tangible into nowadays society. The modular structure of the model enables the adaptability of any of the modules, whether this be adding or modifying modules and functionalities to suit a wide range of circular supply chain situations. Therefore, it is recommended to consider the final MCSC model as a template which can be adapted and changes depending on specific characteristics of the project or stakeholder demand.

From a production environment perspective, it was observed that traditional processes may need changes. For instance, the design phase is needed to consider circular design strategies that will enable the following processes to achieve them. Other examples, is the analysis of an existing building through a big team of specialists or additions of reverse logistics that return secondary building components in other life cycles. The process level identified just some changes into the process and what each entailed. In addition, the test case of Edge Olympic noted that the MCSC model can adapt and be modular depending on the case specificity. Therefore, it is recommended to see how these processes change depending on diverse projects, such as housing, commercial, office buildings, infrastructure and many more.

From the organisation environment perspective that the client had an important role in the determining of the project outcome. Currently, there is not a lot of demand from clients to initiate circular projects, although other supply chain stakeholders know how to deal with it. The case of Edge Olympic shows the importance that the client had in the project outcome due to the ambition of circular building. Therefore, it is recommended that in the initiation phases the project team should advise and direct the client towards the possibility of circular building. In addition, the research showed that traditional stakeholders are interested and investigating the concept of circular building and its supply chain. This has resulted in some stakeholder adapting their business models in way that encompass circular specific roles i.e transformation agent, dismantler companies, or circular experts. Therefore, it is recommended to review these new rising stakeholders and analyse how business models could be changed towards circularity. By understanding such business models and identifying how profit could be achieved, it incentives more companies towards this route. This is necessary to align as many stakeholders towards this ambition within a supply chain, in order for the circular supply chain to be utilised to its full potential.

The control environment revealed the many different tools that are currently available in the market, together with requirements that such environment needs to establish a circular supply chain. General shortcomings of these tools were identified, but it is recommended to further research also the potentials that they have and how they could be better integrated into assisting the supply chain. These tools have the potential to support decision-making moments in design and manufacturing phases, but also could support a more efficient coordination and information sharing between the stakeholders. Lastly, the social environment perspective regarded the legal, financial and cultural factors of the circular supply chain. This research briefly touched upon them and explored the general situation and shortcomings within them. However, these are three very critical contextual dimensions that have a high influence into the establishment of the whole circular supply chain. Therefore, it is recommended that each of this dimension is further and in detail explored by the stakeholders or other researchers.

8-3 Limitations & Future Research

This section elaborates on the limitations of the research based on three areas, theory, methodology and application.

In regards to *theoretical limitations*, further development and testing is needed on the theoretical framework proposed in this thesis. Due to time limitations the analytical model was only tested with one or two representatives of a building case. It would be interesting to test this framework and whether other variables emerge when being tested by multiple different focal companies with the same organisation type in the supply chain. In addition, the four theoretical environments were generalised on a number of variables. However, more extensive research is needed not only to see if there are other variable, but also deepening the knowledge per variable, for instance the legal, financial and cultural factors of a circular supply chain. The control environment needs to be also further developed as it was currently based on a limited number of literature sources, and other sources could be researched and identify changes or additions into these variables.

Methodological limitations, first align with the sampling consisted of eight stakeholder organisation types and 15 representatives. This provided a significant overview on the different process phases and within the direct and indirect environment of influence. However, some of organisations types had only one representative due to time restrictions. For this thesis it was noticed that even for the stakeholders with two representatives, little differences between the two were found. Therefore it is recommended that future research take into consideration other method techniques besides the interviews, such as focus groups or surveys. Furthermore, the MCSC model was validated only based on one test case (Edge Olympic), which showed that the model is modular due to the project requiring them to shifted around. The case had incorporated both transformation and new built processes. However, one test limits the validity and the MCSC model should be tested against other diverse project in order to better verify its modularity and scenarios when it's only a new built or a transformation project. Furthermore, due to the time constraints and Covid-19 pandemic it was challenging to establish observations, and all interviews were held online. Although, this created flexibility and the ability to organise the interviews, it also brought issues such as bad internet connectivity in one of the interviews, which led to the loss of some parts of information.

Lastly, in regards to the *application limitations*, the thesis held a general focus in order to establish the basis of a modular circular supply chain model, acting as a canvas for more specific adaptations depending per building project. Further research is needed to test and validate its flexibility towards adapting to different project types, such as commercial, residential or other segments of building.

The thesis leaned heavily on understanding the supply side of a construction project. More research needs to be undertaken on the demand side and its cultural, financial or regulatory context of the building. Although the regulatory was touched upon through the municipality interviews, there needs to be more detailed research on the different types of departments of municipalities. Further research in clarifying financial impacts and needs towards a circular building project are necessary to clarify stakeholders on the potentials or how to address the risks of such projects. A better understanding of these factors will help better understand the conditions and obstacles to the applicability of a modular circular supply chain model.

Chapter 9

Reflection

In this chapter a reflection on the overall graduation process is provided. First, the research topic is discussed, where the relationship to the master program is provided. Next, a reflection on the methodology that the thesis adopted is done, together with some ethical considerations. Lastly, the personal graduation process is described from the student's perspective.

9-1 Research output

Research product

At the beginning of the research the research gap needed to be established within the research topic. The building supply chain context was the main context where the graduation thesis lied upon. To define the research gap a systematic approach was taken where various literature sources and theories were read. This helped create a deeper understanding into the background of the supply chains. The scope of the research was relatively narrow in the first phases of the process, highly focused on the concept of cross-chain control centres. However during the literature review it was observed that the concept of circularity and specifically circular supply chains is neither established within theory or practice. Thus, fragmented information is available on the topic. Similarly, the control environment is also fragmented and little to no academic research was found on how effective the developed circular building tools are in facilitating a CSC environment. Therefore, this research gives insight into the requirements to create a circular supply chain and dynamic relationships between process phases, organisation types and the control environment.

Dong et al. (2019) argue that there is a need for a model that will coordinate and motivate all involved actors into a joint effort to implement circularity in supply chains. Supply chain modelling represent supply chains in a neat and simplistic way. However, in order to capture the dynamic complexities that the practice holds, the model explore in detail three levels: process, product and organisation. The proposed model that derived from this thesis provides comprehensive findings that complimented the existing research on the topic.

Position within Management in the Built Environment (MBE)

The thesis research was undertaken as part of the Management in the Built Environment (MBE) master track. Different from other tracks MBE focuses on managerial aspects and integration of processes between various disciplines in the built environment. Among others,the Design & Construction management is one of the main departments within MBE, which focuses in the project and process management of the building industry. In its core this thesis focuses on supply chain management (SCM), which is a component of the whole DCM research field. Several researchers investigate this environment, recognising its complexity and underlying peculiarities compounding the management of the overall process. In addition, the building industry has been evaluated to have a significant impact on pollution emissions, which does not align with the governmental ambition to become a circular environment by 2050. In order to facilitate the creation of a circular construction industry, there is a high need for solutions that close product systems together with the information flows running through them, that now 'leak' and waste materials due to the current classic linear approaches.

9-2 Research process & methodology

The research initiated in September with a systematic research on the existing theory, which than was followed by an empirical analysis. The graduation process formally consists of five main presentation moments, which act also as progress benchmarks. To achieve the objective of the research a planning was made based on these five appraisal moments (Figure 9-1).

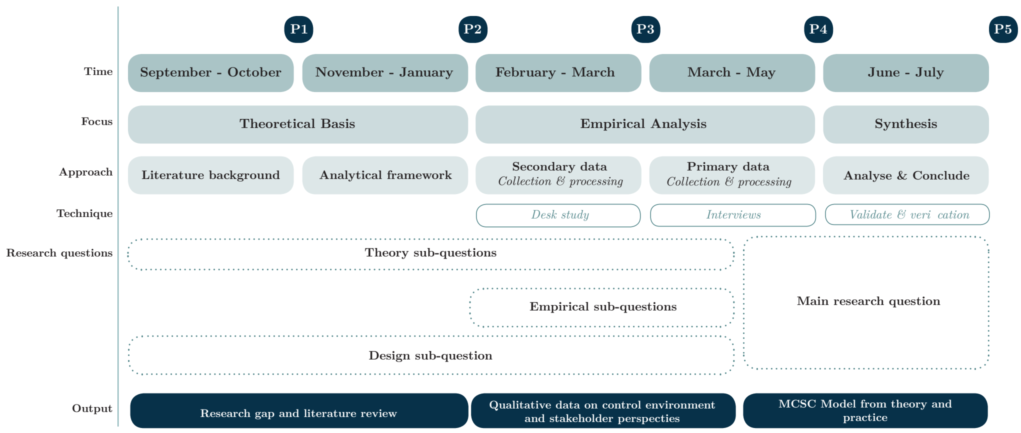

Figure 9-1: Graduation research process planning

The research investigated the basic requirements needed for creating a circular supply chain facilitated by a control environment. The main aim is to test the theory and understanding on what the current situation is, what limitations are encountered and what are the main components encouraging this environment. The research used an empirical methodology, which explored and brought together fragmented information on the topic of circular supply chain and control environment.

The three parts of the research

The research consisted of three parts. The first part consisted of a literature study where the theoretical areas of circular supply chains production, organisational structures, control environment and social environment was analysed. The literature review made use of different sources, such as scientific papers, academic reports and books, which were selected with the help of key words like: supply chain management, cross-chain control centres or circular built environment. The literature review concluded into an analytical framework, which was tested throughout the research. In hindsight, this framework took longer to be finalised, and more research should have been done during P2 on framework examples from sources. Next, the empirical part of the research was conducted. It first started by identifying the current information systems and circular building tools present in the Dutch building context. Then, a case study analysis was conducted. The first approach towards the empirical part was to select a number of building projects based on a specific criteria. However, this approach changed due to the research aiming to overview different representatives from the supply chain, who have experience with the concept of circularity. Beside ensuring an overview of the different phases of the process, the cases collectively present the entire supply chain. The data was collected based on semi-structured interviews. Due to time constraints some cases consisted of one representative. In these cases secondary data from websites, or other commercial documentation was collected to fill in any gaps.

Verification and validation

Large data information was gathered from the 15 interviews within the building cases, which resulted in long textual transcripts. To analyse and derive concise results to be used for the development of the MCSC model, each of the cases was individually described and based on this description the funnelling of the data was possible by organising them in tables for a better overview. Through this tabular visualisation, both the within- and cross-case analysis was able to be done, which then allowed for the confrontation between theory and empirical analysis to be more comprehensive. In addition, in order to validate further the proposed model another validation technique was undertaken, that of a real-world test case. Through this test case, the modularity component was able to be verified.

Ethical considerations

The topic of circularity is not considered as a politically sensitive topic. In addition, the exploitative approach of this thesis on identifying the basic requirements of a circular supply chain did not require detailed information from the internal processes of the interviewed representatives. It should be noted that all participants participated voluntarily and were provided with a consent letter, in which the purpose of the research and how the data would be interpreted was explained. All the information extracted by the interviews and its interpretation was presented in a confidential way in this thesis. This is done to avoid any conflicts or compromises on the positions of the representatives to arise.

9-3 Personal view

The Management in the Built Environment master provided me with a rich insight on the management dynamics of the built environment. It encompassed topics like real estate management, economic and the regulatory environment of a building project and the complexity of the overall design & construction management of the built environment. Due to my fascination with solving complex problems I was eager to learn more about the design & construction management processes. During the master track, building supply chains were briefly touched upon, particularly about the main phases and stakeholders of the supply chain, which invoked my interest in learning more and understanding this environment better. Based on literature I was introduced to the complexity that lies in supply chains together with its peculiarities and inefficiencies. Furthermore, the topic of circularity was another fascination of mine. My first encounter with the topic was in the bachelors through articles and academic papers and during an internship, where the ambiguous nature of the topic was observed. The thesis research ended up being a mixture of these two fascinations together. My ambition was to help make a better understanding of what a circular supply chain environment means and how can one facilitate it.

During the first semester, as part of the curriculum I was following courses, which made the period until P2 significantly intensive. In the period towards P2 the theoretical background was conducted which gave me a lot of insight into the topic. During this period the possibility to find a graduation internship was entertained. However, due to the topic and research ambition this idea was dropped, in order to maintain the flexibility and not focus on one company perspective.

Reflecting back on the period from P2 to P4 the graduation process was fairly challenging due to several factors. First, most of the researches conducted until now were of a smaller scale compare to this thesis. I had little experience with conducting extensive research and other activities like properly analysing and coding interviews. This made me underestimate the time I needed to conduct and analyse the gathered data. In hindsight, I would probably have approached interviewees earlier in the process and have two rounds of interviews with them. Although I felt fairly clear on where this research was aiming towards, it was not until the moment of P3 that the approach became comprehensible. My research process did not follow a linear line, but had a circular iterative approach, which complemented the topic of circularity. This is mainly seen in the development of the MCSC model, which already started since the phase of P2 during the literature review. It also acted as a testing ground during the interviews to grasp the different stakeholder perspectives. The model was continuously adapted based on theory, secondary and primary collected data, which required continuous revision of the modules. Due to this, concerns were raised whether everything would come together in time and whether the level of detail on the data collected would be achieved. In addition, the COVID-19 pandemic had a significant strain on my productivity and anxiety. The pandemic and not following courses during this period, resulted in little communication with fellow students, which I am now aware highly supports my learning experience. However, in the last stages of the phase towards P4 this became better as more communication was established between the graduate students.

Overall, this graduation process has made me aware that a research process is very dynamic and one needs to adapt and be flexible to changes. I believe that I have managed to still reach my main goal of providing a clear overview of what a circular supply chain is and what are some of its requirements.

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Appendix A

Additional information from theoretical framework

A-1 The logistical discipline within supply chain management

SCM has a multi-disciplinary nature, where an integration is done between production and logistical processes. The interrelation between SCM and logistics is a interesting topic of discussion, as supply chain management integrated the strategic goals into the process, whilst logistics provides the operational activities of production and delivering products to the customer (Ivanov & Sokolov, 2009). In analysing the existing research literature, logistics can be defined as *the process of planning, implementing, and controlling the efficient, effective forward and reverse flows and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements* (Council of Supply Chain Management Professionals, 2013, p. 117).

Logistics is considered as an important discipline in SCM as it deals with the optimisation of physical transports. According to Buck Consultants International (2020) construction logistics is the major provider of transport volumes, where approximately 70% of it is realised on roads. Quak et al. (2011) state that for instance in the municipality of Amsterdam, this transportation on roads accounts for 30-40% of all traffic. In addition, Buck Consultants International also provide an estimate of the five most transported goods and materials and the amount of CO_2 emissions related to these activities, see Table A-1.

The measurement of the CO_2 emissions related to these product groups were calculated based on the weight and distance of distribution. From Table A-1 it is seen that the majority of transportation weight and highest emissions are related to the materials that make up the structure and site layer of construction. In addition, other high levels of emissions come from other construction materials, which are provided for the space plan or skin layers of construction. Seeing, that logistics has a significant influence on the environment, it is important to identify the challenges and barriers that are currently present in construction logistics.

Table A-1: Top five transported product groups

Product group	Weight	Distance	CO_2 emission
Stone, sand, gravel, clay and other minerals	47%	5%	23%
Residential and municipal waste	4%	4%	4%
Other equipment, machinery and parts	5%	13%	9%
Other construction materials and products	30%	23%	42%

Some challenges and barriers are tightly related to the peculiarities of the building industry. One of the crucial components of SCM is coordination. However, Lundesjö (2015) criticises the construction industry process as being uncoordinated and wasteful, which is resulting in higher logistical distributions than required. This is quite alarming seeing the high impact that logistics may have in the environment. In addition, Balm et al. (2018) argue that this uncoordination is due to an unclear division of responsibilities between the construction site and supply chain actors. This creates congestion and delays on the construction site. Another element influencing the lack of coordination is insufficient planning, whether this is a byproduct of no clear responsibilities or just lack of data and proper information or miscommunication between the different stakeholders of the project (Balm et al., 2018). Furthermore, de Bes et al. (2018) states that the logistical activities are often not known by other construction companies involved in the project. Therefore, there is a high need to enhance this coordination in order to avoid all its negative outcomes, such as time delays, additional cost and added risks (Lundesjö, 2015). According to Ivanov & Sokolov (2009), the basis of coordinating an efficient supply chain is through ICT systems, within which functionalities such as SC planning, monitoring or trace and tracking are needed. Hence SCM being interlinked with not only logistics but also informatics and engineering (Ivanov & Sokolov, 2009).

Collaboration is another challenge within construction logistics, which often occurs due to the uncoordination. Due to the complexity and temporary nature of the supply chain and the high number of directly and indirectly involved stakeholders, it is often difficult to establish an integrated collaboration (De Bes et al., 2018; Tesselaar, 2020). Each of these stakeholders bring their personal requirements thereby influencing the project. Therefore, more attention need to be allocated on supporting ICT systems that can help provide a more coordinated and collaborate construction logistics and supply chain management as a whole.

A-2 A summary of circular economy definitions from main sources

Table A-2: Circular economy definitions from main sources

Source	Definition of circular economy	Journal published
(Prieto-Sandoval, Jaca & Ormazabal, 2018, p.610)	"an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes."	*Journal of Cleaner Production*
(Geissdoerfer et al., 2017, p.766)	"a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, re-manufacturing, refurbishing, and recycling. Second, we define sustainability as the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations."	*Journal of Cleaner Production*
(Ness & Xing, 2017, p.572)	"the circular economy (CE) concept seeks to extract more value from resources by using them for as long as possible, thereby increasing economic prosperity and employment while reducing waste, greenhouse emissions, and pollution."	*Journal of Industrial Ecology*
(Bocken et al., 2016, p.317)	"The recognition of the limits to planetary resource and energy use, and the importance of viewing the world as a "system" where pollution and waste are viewed as a defeat, lay at the foundations of circular thinking."	*Journal of Industrial Ecology*
(Stahel, 2016, p. 435)	"A 'circular economy' would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimising waste. It would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused, repair what is broken, re-manufacture what cannot be repaired."	*Nature News*
(Gregson et al., 2015, p.223)	"(...) circular economy seeks to stretch the economic life of goods and materials by retrieving them from post-production consumer phases."	*Economy and society*
(Haas et al. 2015, p.765)	"The circular economy (CE) is a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes by closing economic and ecological loops of resource flows."	*Journal of Industrial Ecology*
(The Ministry of Infrastructure and Environment, 2014, p.1)	"an economic system that takes the re-usability 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"	-
(The Ellen McArthur Foundation, 2013, p.7)	"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."	*Journal of Industrial Ecology*

A-3 Building layers and its life-cycles

Brand (1994) identifies six layers comprising a building. First, the *site* is understood as the geographical ground and surrounding where the building rests on. The *structure* layer make up the foundations and the primary components that hold the load of the building. The *skin*, on the other hand, provides the visible layer that dresses the structure, such as the roof cladding, or the finishing material of the facade. Next, the *services* layer, holds all the plumbing, electrical wires and other mechanical components that allow the building to function. The *space plan* differently from the skin, provides the indoor material finishes and furniture. Lastly, the *stuff* layer, are the mobile furniture and elements that comprise the space plan of a building. In addition, the life-cycle spans of the different layers are provided in the table below, based on eleven different sources.

Table A-3: Life spans of building layers in years and their sources (adapted from Crowther, 2001, p.10)

Layers	**Life-cycle estimations (in years)**										
	Cook (1972)	Kikutake (1977)	Duffy (1989)	Tucker (1990)	Brand (1994)	Howard (1994)	Storey (1995)	Curwell (1996)	McCoubrie (1996)	Adalberth (1997)	Suzuki (1998)
Site	*eternal*										
Structure	40	25-125	50	40	60	65	60	60-100	40	50	-
Skin	15	25	50	12-30	20	65	20	15-40	36	30-50	15-30
Services	3	5	15	30-40	7-15	10-40	7-15	5-50	33	12-50	7-30
Space Plan	5-8	5	5-7	8-40	3-30	5	3-5	5-7	12	10	-
Stuff	-	-	1-5	-	1-5	-	-	-	-	-	-

A-4 Circular supply chain definitions based on revised papers

Table A-4: Definitions of circular supply chains

Source	Term	Definition	Journal published
Hussain & Malik (2020)	Circular supply chain (CSC)	"we conceptualised CSCs as the future high performing state given the CE's established links with Strong Sustainability."	*Journal of Cleaner Production*
Singhal et al. (2020)	Circular supply chain	"the application of circular supply chain concepts helps the organisations in making efficient use of the resources and results in the increased value to the society."	*Resources, Conservation & Recycling*
Govindan et al. (2020)	Closed-loop supply chain	"Incorporating CE into SCM could extend the boundary of sustain-ability through reducing the need for virgin materials, which con-tributes to circulation of resources."	*Journal of Cleaner Production*
Farooque et al. (2019)	Circular supply chain	"Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically re-stores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service life cycle including parts/product manufacturers, service providers, consumers, and users."	*Journal of Cleaner Production*
de Oliveria et al. (2019)	Circular supply chain	Circular supply chain (CSC) is considered an umbrella term for the coordinated forward and reverse supply chains, in order to develop several reverse cycles such as reuse, repairing, reconditioning, re-manufacturing, or recycling which are integrated back into forward supply chains.	*Journal of Cleaner Production*
Zhu et al. (2019)	Closed-loop supply chain	"enables waste products to be professionally restored to the same quality and performance as new products and is considered to be the most valuable product recycling method."	*Sustainability*
Lüdeke-Freund et al. (2019)	Closed-loop supply chain (CLSC)	"CLSCs cover different kinds of forward and reverse material flows together with related immaterial flows (mainly information and money) as well as the coordination of these flows(Govindan et al. 2015). CLSCs also address the relationships and collaboration between different economic and non economic actors (Schenkel et al. 2015; Rodrıguez et al. 2016), and related company and supply-chain–spanning resources and capabilities (Miemczyk et al. 2016) that facilitate the forward and reverse flows	*Journal of Industrial Ecology*
Taghikhah et al. (2019)	Extended sustainable supply chain (ESSC)	"The ESSC framework assumes that other managerial techniques should also be employed, with focus on the social dimension, on education, motivation, nudging and persuasion as part of development towards sustainability."	*Journal of Cleaner Production*
Prosman & Sacchi (2018)	Circular supply chain	"Circular supply chains include forward supply chains and reverse activities."	*Journal of Cleaner Production*
Geissdoerfer et al. (2018)	Circular supply chain management	"We use the term circular supply chain management (CSCM), which comprises the configuration and coordination of the supply chain to close, narrow, slow, intensify and de-materialise resource loops."	*Journal of Cleaner Production*
Leising et al. (2018)	Circular supply chain & collaboration	"as connecting a network of actors in their supply chain by managing data transparency, material flows and exchanges, responsibilities, predictability and sharing benefits."	*Journal of Cleaner Production*
Geneoveze et al. (2017)	Green & sustainable supply chain	"green and sustainable supply chain management practices have emerged, trying to integrate environmental concerns into organisations by reducing unintended negative consequences of production and consumption processes	*Omega*
Masi et al. (2017)	Circular supply chain	"Supply chains are assumed to be a critical unit of action for the implementation of the CE because of the necessity for joint effort "beyond organisational boundaries to involve external coordination with upstream partners to obtain environmentally friendly inputs and with downstream partners to cooperate for environmental management practices such as product return, reuse, and recycling."	*Sustainability*
De Angelis et al. (2017)	Circular supply chain	"as the embodiment of circular economy principles within supply chain management"	*Production Planning & Control*
Nasir et al. (2017)	Reverse supply chain	"The principles of circular economy thus extend the boundary of green supply chain management by devising methodologies to continuously sustain the circulation of resources within a quasi-closed system. (...) as a series of activities that are required in order to retrieve a used product from a customer and either dis-pose of it or reuse it."	*Int. J. Production Economicshttp*
Guide & van Wassenhove (2009)	Closed-loop supply chain	"Closed-loop supply chain management is the design, control and operation of a system to maximise value creation over the entire life-cycle of a product with dynamic recovery of value from different types and volumes of return over time."	*Operations Research*

Appendix B

Additional Information from Empirical Findings

B-1 Interview Protocol

Topic: A modular framework for integrating circularity in building supply chains

Interviewer: Kristi Fishta |

1| Setting up interview protocol

This interview protocol will be a semi-structured interview that will focus on the following research sub-question:*How is the MCSC theoretical model perceived by organisations active in the building industry?*

Based on this research question, it is noticed that the *keywords* are: 5C concept, construction industry, supply chain, organisation functions.

Reasoning

According to Yin (1984), there are three main data types of evidence used while conducting a qualitative research: interviews, observations and documentations. By using multiple data sources it is argued that it will result in increased reliability of the research, while the use of multiple data collection methods is thought to help sustain the objective of this thesis. Therefore, this research heavily focused in collecting data based on both documentations and interviews.

The data provided from the interviews can be collected through three different interviewing types: (i) open, (ii) semi-structured and (iii) fully structured interviews. The latter is mainly used when the researcher has complete knowledge and the collected data is expected to deepen the knowledge on the topic, based on a predetermined list of questions (Turner III & Daniel, 2010). On the other hand, the open interview type has a significant exploratory nature on a topic researched (DiCicco-Bloom & Crabtree, 2006). This interview type follows a free-flowing conversation and is not based on specific questions, which may encourage biased information. Lastly, a semi-structure interview type is a mixture between the two aforementioned types. Instead of a full list of questions, a set of themes act as guidelines for the conversation, whilst maintaining an exploitative nature on the perspectives of the interviewee. The guiding themes ensure that the needed data is gathered whilst mitigating the risk of biased answers. As the concept of circular supply chains is not yet established in literature and practice, the semi-structured interview type is considered as most favourable for this thesis.

Goal of the interview

The goal of this interview is to obtain insight on the implementation of circularity in the supply chain, and manners on how to achieve an integrated supply chain, particularly integrated information and material flows. Through this interview I would like to gather information on how practitioners perceive this new 5C concept and based from their experiences what are some crucial needs and requirements for creating a circular supply chain and a centralised information flow.

Time of holding the interviews

All interviews are scheduled within a 60 minute time-frame.

Privacy

According to the new data and privacy regulations of TU Delft each of the interviewees is provided with a consent form and asked to fill in before the interviews are held. These consent forms will be gathered before the interview.

Medium for conducting the interview

Due to the COVID-19 pandemic, it was decided for the interviews to be conducted online through digital mediums. When contacting the interviewees to confirm the date and time three platforms were provided for them to choose from: Zoom, Skype or Microsoft Teams. Thus, giving the participants the possibility to choose a platform that they are familiar with and feel most comfortable with.

2| Semi-Structured Interview main themes

Here the main themes of discussion are introduced. The aim is to let the interviewee tell their stories, experiences and inputs in a free conversation. However, in order to make sure that the needed information is gathered a few questions are formulated which cover the main themes of this interview. Each theme will have an estimate time, in order for most of the questions per theme to be addressed. During the interview However, it is taken into account that small deviations could happen from these questions as it will be a semi-structured interview.

Setting the tone of the interview

During this first step the interviewer's main goal is to set the tone of the interview by taking the lead and trying to create a comfortable and trustworthy environment.

- Introducing oneself (Name, study, graduation topic)
- Asking pre- and on record permission to record the interview.
- Reminding the interviewee on the time and structure of the interview. Also provide them with the option of skipping a question in case one feels uncomfortable to answer.
- Providing background on the research topic; Introduce the concept of the MCSC model, which will be reinforced by providing images of the theoretical MCSC model (Section 4-7)

General Questions

Here the respondents are asked to introduce themselves and their current situation in their company environment.

- Could you elaborate a bit on your position and responsibilities within your organisation?
- What type of projects is your company most involved with?

Circularity related questions

- What is your understanding of a circular supply chain?
- What initiatives and operations is your organisation/company taking in the implementation of circular strategies internally?
- Could you please elaborate on how your company collaborates with external companies for a circular project?

Supply chain organisation related questions

- Looking at the MCSC model in which phase of the supply chain project process is your organisation most active in?
- Perception on reverse loops: In your knowledge, which parties are the most crucial to facilitate these loops and will new actors, information or new tools need to be introduced into the process?
- What is your perception in having a more integrated start of the project?

Control environment related questions

- What type of systems and technologies do you currently use for storing information and could you elaborate what type of data lays in these systems?

- There have been several circular tools developed and presented in the market. Do you make use of any of them?
  - If yes: which ones and what benefits have you noticed?
  - If no: what are the reasons for this? Is it because you miss specific functionalities in these tools?
- What are some functionalities that would you see as crucial for the control environment to have in developing a circular supply chain?
- Which stakeholder(s) are in your opinion crucial to facilitate this control environment?

Control environment related questions

- What are some constant barriers, specifically in regards to information availability that you have encountered in your projects when implementing circular strategies?
- What is the willingness of your company to share the data that is stored in your information systems?
- In your opinion what would be the perfect conditions for your organisation to be willing to share data in regards to the project details?

Finalising interview The interview will end by thanking the interviewee for taking part in the interview. Additional arrangement could also be discussed, such as asking whether the interviewee wants the recording of the interview. Some closing questions:

- Are there any additional remarks on what we just discussed?
- Are there any documents that you could potentially share with me related to your organisation?

3| Conclusion interview protocol

The main themes of this interview protocol will be used during the interviews and the questions will be taken into account if needed depending on the interviewee's answers. It is expected that additional question may rise during the interview and depending on the function of the interviewee.

B-2 Interview Coding List

Before the analysis of the cases could be conducted, the interviews were transcribed and coded. The coding process enables for the qualitative data to be congregated, categorised and thematically ordered, providing an insightful overview of the organisation of the empirical findings. A list of the coding process is provided in the following table:

Table B-2: Overview of coding list based on open, axial and selective themes of the building cases.

Open coding	Axial coding	Selective coding
Derived from many segments of text	*Derived from categorising open codes*	*Derived from theoretically ordering the axial codes*
Transformation project processes New-built project processes Involvement with adjacent supply chain process Change of business processes to match circular strategies Modification of materials/products before sale -purchase activities	Operation and process coordination	Production environment
Perception of circular supply chain Open loop Closed loop Agreements with set of partners to return products and materials Returned materials should be certified New circular specific stakeholders in return loops are needed	Circular reverse loops	
Specific design strategies Integration of stakeholders in earlier process phases Engaging all supply chain stakeholders towards circular building	Strategy integration	
Internal organisation in collectives Organisation in action teams for establishing working agreements Incorporating circular hubs internally Transition of internal organisation to achieve circular ambitions Adopting new business activities from circular-specific roles	Internal alignment	Organisation environment
Long-term collaboration with key suppliers/manufacturers Coalliances to assist in key business functions Joint product/service devleopment Negotiation to reach consensus within the supply chain about circularity	Cross-chain collaboration	
Open information and knowledge sharing with externals Willingness to share information through filtering of some data Maintenance of competitive advantage	Information exchange	
Draw up and storing of material passports Quick responsiveness to changes in leading processes Information systems for process support Constant updating of information and process changes Monitoring of data being accurate	ICT architecture requirements & functionalities	

Table B-2 continued from previous page

Open coding	Axial coding	Selective coding
Governmental bodies Own chain stakeholders New independent actors	Control facilitator across supply chains	Control environment
Benefits of circular tools Helpt winning a tender Integrating new circular tools to assist internal processes Development of new technologies to help with controlling and monitoring product flows	Circular building tools	
Lack of support from governmental regulation Minimum calculation requirements Support of initiatives coming from private market parties	Legal variables	Social environment
Retaining market advantage Products and materials issued with monthly/yearly profit returns Larger investments from transformation projects Increase of investment costs Long-term profit returns	Financial variables	
Change of cultural mindset Organisation and process adaptation Lack of urgency to change towards circular building	Cultural variables	

B-3 Brief description of the circular building tools

(1) Building Circularity Index (BCI): measures the circularity degree of a real estate object. In addition, it is able to be collaborate with Madaster Platform, to generate a material passport. By doing so, it enables the tracking of several characteristics, such as origin, waste scenario and the detachable level. The aim of this tool is to optimise the real estate object in the field of circular building, in regards to material choice and the connection abilities of these materials (Alba Concepts, n.d).

(2) Circle Assessment: developed by Circle Economy, is a tool that aims to assist different companies to be more conscious in the impact of their operational and organisational decisions in regards to circular economy. For the assessment, Circle Economy has defined seven key indicators that are thought to have direct circular handling of material and energy flows: collaboration, use, preserve, design, prioritise, incorporate and rethink. Based on the evaluation of each individual indicator a total score is calculated, providing companies with a clear estimation on how circular their business is and educating them on potential circular opportunities to explore further (Circle Economy, 2018).

(3) Circular Building Assessment (CBA): is a tool that evaluates material and product flows during the life cycle. This tool enables companies to compare different design possibilities on their level of circularity. Another crucial aspect for CBA is its ability to collaborate and exchange information with other platforms, such as BIM, CAD files or other software. Through this collaboration CBA is able to extract relevant information, like quantity data input by the user, relevant bill of quantities and material data, which are needed for the assessment of the proposed design options. The main goal of CBA is to show stakeholders that the evaluation of a building can start since the early stages of design until the delivery phases, by assessing the design options in a semi-automated environment, utilising available data from other model software, or providing a foundation of assumed data where there is a lack of it. In addition, based on a scale between 0-100%, an assessment is provided of the reuse potential of design decisions and material selection criteria (BAMB, 2018).

(4) Circulair IQ transition indicators (CTI): was developed to help businesses of different industries to measure and improve their circular performance by supporting and guiding them during their transition to a circular economy. CTI is highly based on the analysis of the material flows of a business, and measuring how circular these organisations are. Based on three indicators (Close the Loop, Optimise the Loop and Value the Loop), each with a range of sub-indicators, business are able to choose the most relevant indicators to measure their circularity score, which is represented in 0-100% scale for the first two indicators and in a low-high scale for the third indicator. The tool structures data and calculates outcomes, while simultaneously supporting businesses in taking concrete actions towards their circularity goals. Furthermore, it also supports collaboration with internal and external value chain partners to share data whilst avoiding confidentiality issues (Circular IQ, n.d).

(5) Circular Design Guide: The process of designing is seen as a crucial element in the development of a circular economy. Therefore, the Ellen McArthur Foundation created the Circular Design Guide, a free platform for designers to review a variety of guidelines and principles related to circular designing. The guide is a compilation of additional tools, methods and resources that are expected to assist in all stages of design. All of these are categorised based on four themes: understand, define, make and release. The Circular Design guide aims to inspire designers with new innovative ways of designing which align with the circular economy principles (The Ellen McArthur Foundation, 2018).

(6) Circular Economy Index (CEI): was developed in order to address the on-going issue of inefficiency when recycling materials and products. In order to calculate the CEI, this tool proposes a ratio between the value of materials generated by recycling and the value generated by the material entering the recycling process. It is necessary to obtain the exact data basis of the end-of life-products and materials entering the process in order to have a significant evaluation of circularity. The tool regards economic, strategic and environmental aspects of the recovery process by presenting quantitative results (Di Maio et al., 2015).

(7) Circularity Calculator: was developed by IDEAL&CO Explore, with the help of manufacturers that have experience with circular economy, simultaneously validated by case studies from the Ellen McArthur Foundation. This tool's main aim is to evaluating the level of circularity in products, and assessing weakness in the process. By making use of a point-and-click dashboard, it is possible to show three different cycle flows: (i) refurbish, (ii) re-manufacture and (iii) recycle, whilst calculating financial values of closing the loop.

Four key performance indicators are used to visualise the gathered results per product in a percentage scale, which relate to the circularity of products, value capture, recycled content and reuse index. With these indicators the design process and business models can be compared and evaluated based on the circularity component (IDEAL&CO Explore BV, 2017).

(8) Circularity Check: is an online scanning tool which uses a questionnaire of approximately 60 questions to determine a circularity score on a specific product/service. Each question is individually assessed with a score between 0-100% based on 5 indicators, which later is calculated in the total outcome, again in a % normalisation. The five indicators used for the scoring are: design/procurement/manufacturing, delivery, use, recovery and sustainability. In addition to the score, this tool provides business with certain recommendations on the actions to take to improve their performance on circularity (Ecopreneur, n.d).

(9) Circulator: was developed by EIT Raw Materials, with the aim to support entrepreneurs and businesses in making conscious strategic choices regarding the circularity of their business model and value proposition. The tool allows these businesses to navigate through potential circular strategies as well as relevant case studies to learn from. The core idea of Circulator is to create a mixture of circular business strategies that aligns most with the concept of one's company. These strategies have been grouped in three categories: (i) sustainable materials management strategies, (ii) business strategies and (iii) value network strategies. In addition, four indicators have been identified that are seen as the main entry point for developing a circular business model. Each represent a different business focus, such as focus on the customer, on the product/process, on the value network and on sustainable identity (EIT RawMaterials, n.d).

(10) Circulytics: The Ellen McArthur Foundation developed this tool to support companies during the transition towards circular economy. It goes beyond the product level to the company level, revealing the extend the operations of a company comply with circularity.

A circularity score (from A to E) is assigned to companies by taking into consideration two main indicators, which have sub-indicators. The first indicator, the "enablers" tackle five different themes, such as types of strategies, innovation, people and skills, systems and external engagement. On the other hand, the second indicator, "the outcomes" addresses only two themes: inputs and outputs.

The Circulytics tool increases the awareness between companies on the importance of considering environmental and social impacts when developing their business strategies. Currently, the information gathered in this tool is confidential and not shared with any third parties. However, on the of the goals of this tool in the future is to annonymise the information and use it to generate industry benchmarks and with the permission of companies use some of this information as inspiration case studies (The Ellen McArthur Foundation, 2019).

(11) Closing the Loop by Design (CLD): When designing a product that will be restored at end-of-life, it requires for considerations of aspects, like type of materials or types of connecting components before decisions are made. According to Remeha (2018), the products of today become the resources of tomorrow, therefore they developed the CLD tool. The Closing the Loop Design aims to assist in the design process of new products in order to enable the ability to be reused, refurbished and recycled once their first service-life has ended. Through four indicators (architecture, component, connection and material), holds a set of design guidelines, which help companies in the designing and production of products that circular proof. These guidelines should be seen as points that inspire new ways of thinking and create awareness, instead of literal points of direction (Remeha B.V., 2018).

(12) Dutch Property Inspections: is in essence a company that is focusing in creating these multi-year plans for different types of properties. The process starts by first identifying any past or future problems related to the building, based on documentations in the municipal achieves. Then a timeline and cost estimate is formulated for the inspections, structural/technical maintenance or replacement activities that need to be done, both in short- and long-term. Although it is not a software tool, the maintenance reports created by this company assists the creation of a circular environment by prolonging the life cycle and value of products in a building (Dutch Property Inspections, n.d).

(13) Eco-Cost Value Ratio (ECR): is an LCA based tool which has been developed to analyse potential negative impacts from business initiatives to the surrounding environment, and consequently designing a more sustainable business model. The tool provides companies with quantitative information on costs, market value and eco-costs, in regards to their future decisions. Within this tool, two methods are applied for the purpose of analysis and designing: Eco-efficient Value Creation (EVR benchmark) and Circular Transition Framework (analyses stakeholder activities in regards to the transition of sustainable business models). The EVR tool seems to be a helpful tool during the process of designing circular business models by considering various environmental aspects of production to the market (Scheepens et al., 2016).

(14) Gebruikte Bouwmaterialen Marktplaats: differently from other tools, it is mainly a web-shop, in which materials and products that are recovered from the demolition phase are resold to be reused in other construction projects. The company starts its process from a more conscious demolishing process, by opting for dismantling (first indicator) rather than demolishing. Next, the recovered products/materials are sorted and a quality check (second indicator) is conducted to identify the proper reuse possibility. Lastly, the materials are place on the web-shob, where they can be purchased by third parties, for the purpose to re-utilise them in other projects (Gebruikte Bouwmaterialen B.V., 2013).

(15) GPR Gebouw: The ambition of building in a sustainable and circular way is the driving force of the GPR Gebouw tool. The tool allows for an analysis to be conducted based on five overarching indicators: energy, environment, health, use, and future value. In addition, a score ranging from 1 to 10 is assigned per aspect, which then are gathered and overall final score is provided. This score shows the performance level of the building in regards to circular principles. The quantitative results make the sustainability of buildings more tangible and negotiable. GPR is mainly a performance-oriented tool, which provides quick and efficient results, suitable while drawing policies and assisting projects (GPR gebouw, n.d).

(16) IMPACT: is a tool for manufacturers in various sectors to make their products more sustainable. Based on quantitative results organisations are able to be informed on the type of resources that are saved during the process of manufacturing and the positive impact this product will have in the environment. In addition, the economic effects are also shown through this tool. It is designed with the ability to collaborate with 3D/BIM software tools and LCA applications. IMPACT is a standardised specification data-set, which provides consistent results in regards to accuracy, reproducible and transparency. Furthermore, the tool allows for the creation of benchmarks which are used within BREEAM and facilitate sound comparisons to happen between different outcomes. The Impact tool, provides its users with a reliable reflection of the buildings LCA performance and credits within BREEAM (TNO, 2019).

(17) Insert Marktplaats: is an online platform where reused materials and products are gathered from the construction site and resold with the purpose to be reused in another project. The harvested products are sorted based on their condition that they are in, the sector that are most appropriate for and the category which they comply to. Through this grouping it is more visible what the available options are for organisations to choose a suitable product for their specific project, simultaneously enhancing the reuse capability and extending the value of these products (Insert, 2020).

(18) Life Cycle Vision: Implementing sustainability and circular ambitions bring forward also economic challenges when making design choices. This tool enables life cycle costs to be calculations for all technical installations in a building to be done. Four types of costs are calculated: purchase, maintenance, energy and demolition costs. The results from these calculations are expected to help improve the decision moments in different stages of a construction project for a installation company. It seems to be the only tool at the moment that addresses circularity in installation technology, by attaching economic value to more conscious decisions, and indirectly achieving also future environmental benefits too (Life Cycle Vision, n.d).

(19) Madaster Circularity Indicator: Madaster is just one of the many platforms that serves the purpose of facilitating circular building and increase the value of the buildings. It is a repository where material and product data is stored which could be looked up anytime when necessary. In addition, this platform utilises the Madaster Circularity Indicator, which allows for a circularity score to be assigned per material or product indicating thus an objective measurement of the circularity level of buildings. The aim of the Madaster Circularity Indicator tool is to improve circularity-oriented building design and increase the circular value of buildings.

According to Madaster (2018), this CI score is the measurement indicator with a range of 0-100% that shows the level of circularity in a building in three different phases: construction, use and end-of-life phase. There are two main indicators for the CI score. First, Building Circularity Indicator, where a CI score of the building is appointed based on the available data. Second, the Madaster Circularity Indicator, which takes the Building CI score and adjusts with two correction factors: unknown materials and unknown building layers. By applying these correction factors, the comprehensiveness of the data-set in the Madaster database is taken into account and as a result a total CI score is calculated. The Madaster Circularity Indicator tool is designed to objectively measure the circularity level of both technical, and biological life-cycles, and to determine a single Madaster CI score, where technical life-cycles are reused and/or recycled optimising high reuse levels and biological ones are materials that are biodegradable at the end of their useful life (Madaster, 2018).

(20) MarketplaceHub: is a tool designed to facilitate the increase of use of sustainable resources through accelerating business to business reuse opportunities for secondary materials worldwide. The map gives an overview of existing materials marketplaces and industrial synergy networks around the world, searched by materials or location. These synergies could contribute to a number of benefits for the companies, such as landfill tax savings, higher resilience, resource efficiency, mitigating extensive CO2 emissions, and improved image and reputation for the company itself. The Hub also provides case studies of marketplaces that successfully addressed some of the challenges encountered operating these platforms. The information in MarketplaceHUB is derived from 18 different countries which have other websites to help with the circularity goals. This tool links to these websites that could help companies to tend to their circularity goals (World Business Council for Sustainable Development, n.d).

(21) Material Circularity Indicator (MCI): was established by the Ellen McArthur foundation & Granta Design as part of the bigger project: Circular Indicators Project. Its main purpose is to encourage European companies to address circularity by evaluating the performance of their products and their business models. By utilising a quantitative evaluation it provides companies with a more tangible approach and simultaneously raises awareness on the added value of addressing circularity in their business models. MCI presents a score form 0 to 1, where scores closer to 1 have a higher circularity level, whether this be regarding products of the business level. The tool mainly addresses the product design stage, but it can also be utilised in the procurement and purchasing choices or housing reports (The Ellen McArthur Foundation & Granta Design, 2015).

(22) Material Reutilization Score (MRS): was developed for the purpose of increasing the re-utilisation potential of products and materials. This tool is thought to address the concept of "waste", which is one of the core aspects being tackled by Cradle to Cradle. This tool is a design approach that addresses aspects, such as safe materials, continuous recovery and reuse of materials, clean water, social equity and renewable. The measuring scale consists of four levels; starting from the lowest Bronze where the product has an MRS of ≥ 35, Silver with an MRS ≥ 50, Gold with an MRS ≥ 65 and lastly the highest is Platinum with and MRS of 100 (Braungart & McDonough, 2009).

(23) Milieuclassificaties Bouwproducten: is a tool that provides relevant information on the environmental properties of various building products and materials. In addition to these properties, an overview of the environmental costs is also provided in this online platform, which is expressed in hidden environmental costs per functional unit. In order to provide clear information on the health of the materials and products an environmental class classification is provided, ranging from 1 to 7 with each obtaining three sub-classes (a, b, c). By doing both the health and economic assessment of products NIBE, developer of the tool, aimed to offer the possibility for companies to make the best choice of materials which are environmentally friendly and financially feasible (NIBE, 2019).

(24) O-Prognose: is a tool that that mainly addresses the utilisation phase of a building. It assists organisation in arranging building inspections and creating long-term maintenance plans, which will help in extending the service life of products in a building. A long-term maintenance plan is regarded also as a measure to control maintenance costs. Therefore, O-Prognose provides insights on long- and short-term costs that are needed to maintain a building, by aligning the maintenance polity with future maintenance costs. In addition, the tool can be utilised also during the preparation and pre-purchase phase and for daily management purposes (Spacewell, n.d).

(25) Optimal SCANS: is a tool developed by Optimal Planet with the aim to assist in the monitoring of products and services of a organisation and enhancing circular purchases. The tool creates a quantitative and tangible calculation for organisations to understand how circular the suppliers considered for a project are. This calculation allows to choose the most appropriate supplier that will enhance a circular project. The total score is calculated based on five themes, such as sector, sustainable strategies, results, actions of sustainability and attention to circular economy. Each supplier considered to be tendered for the project needs to provide information based on these themes, which calculates a total score on how circular each supplier is and allows for comparisons to be made between them. Therefore, Optimal SCANS seems, to be a tool to not only measure circularity but also help different stakeholders to be more conscious in the tendering process of suppliers (Planet, n.d.).

(26) Platform CB'23: was initiated by the Dutch National Roads and Waterways authority (Rijkswaterstaat), the Dutch Central Government Real Estate Agency (Rijksvastgoedbedrijf), and the Netherlands Standardization Institute (De Bouwcampus and NEN) to start the process of dealing with circularity in a joint manner. Being in the initial stage of this transition, raises many questions on what the most efficient to jointly achieve a circular environment. Platform CB'23 (2018) argues that a package of unambiguous agreements are necessary to start the process of a circular construction sector. Currently, these agreements are being drawn up for the residential, non-residential and civil engineering sectors, based on seven interconnected main topics: (i) framework including lLexicon, (ii) circular design & circular construction, (iii) measuring circularity, (iv) information & data, (v) value creation & financing, (vi) assurance and (vi) supply chain transformation (Platform CB'23, 2018).

(27) Product Level Circularity Metric (PLCM): is developed with the purpose of evaluating the circularity level of a product. A metric is suggested based on the ratio between recirculated economic value and product value. The circularity metric is a quantitative method and ranges between a score of 0-1 or 0-100% of recycled elements. The economic value was considered as a basic unit in the development of the metric system of PLCM, which makes this tool a cost-based approach (Linder et al., 2017).

(28) PRP: Another important aspect of circularity is also the creation of a circular process, where procurement and tendering phases are also done in a circular manner. The PRP tool, developed by Rendemint facilitates a circular procurement process based on two main conditions: (i) the product to be purchased is circular and (ii) the product/project is tendered in a circular manner. The tool assists different stakeholders during this process, by answering any potential questions they may have in regards to circular procurement activities. PRP aims to enhance a circular process by assigning responsibility to the purchasing parties which is thought to have far-reaching consequences. There are three stages of consequences: (i) pre-consumer purchase, (ii) utilisation of the purchase and (iii) post-consumer. PRP provides purchasing parties with insights in all three stages, providing them with a total overview of the process, in order to ensure the most circular purchase to be done (Rendemint, n.d).

(29) ReCiPe method: developed by the Dutch Institute for Public Health and Environment (RIVM, 2018), is used to conduct an impact assessment of the product life cycle, which is also known as the LCIA. It is important to study the life cycles of products, as they are connected to a large number of resources and their emission levels. The ReCipe tool enables for life cycle impact assessments to happen, where these emissions and resource extractions are translated into impact scores, which make them more tangible for different organisations. These calculations are done based on a set of characterisation factors, which are grouped in two main indicators: the midpoint and endpoint level. Midpoint indicators focus in addressing individual environmental factors while endpoint indicators deal with higher aggregation areas of protection, such as effect on human health, biodiversity and resource scarcity. Although, the two indicators are complimentary to each other, there is a difference in the level of uncertainty. Midpoint factors have a tight relationship with environmental flows, providing less uncertainty, whilst the converging happens in the end-point factors increasing uncertainty.

The LCIA final evaluation is the converged result between all these factors, which is represented in respective units to the three levels of aggregation. For instance, human health area has a unit in number of years, biodiversity has a (species x year) unit, and resource scarcity is expressed in monetary value (dollars) (RIVM, 2018).

(30) Recycling Index (RI): developed by van Schaik & Reuter (2016) on the basis of simulation models. This tool aims to help companies and organisations to make more conscious choices when purchasing materials and products and produce a sustainable design. It incorporates two main indicators: (i) recycling index and (ii) material recycling index. The latter analyses all individual components of a product and estimates their recovering percentage rate. The higher the rate the higher the closer it brings to a whole circular building (van Schaik & Reuter, 2016).

(31) ReNtry: has no 'score', but aims to makes a clear distinction between circular and non-circular resources. By making this distinction then it allows to further determine how and by whom the resources can be reused at the highest level of quantity and quality. It capture data from the initial and end mass indicators, and compares this data. If (a part of) the end mass is non-circular, then that part is considered as linear. Within linear re-utilisation there are different levels, where down-cycling represents the highest linear level and thermal recycling (incineration) the least. ReNtry is a transition tool in which the actual circular result is measured and generates a true material and resource passport. It should be noted that this tool is part of the procurement and tendering method PRP (Rendemint, 2016).

(32) Value-based Resource Efficiency Indicator (VRE): is a methodology that enables an estimation to be done on efficiency and circularity, which is in alignment with the market value of resources. The indicator can be compared to "mass-based resource efficiency indicators", but with better alignment in the political, environmental and economic policy realms. In addition, the indicator is also characterised by its adaptable, robustness and cost effectiveness nature, which potentially results in an overview of the whole value chain performance. Contrary to the mass-based indicators, VRE focuses in the calculation of monetary value, rather than the mass (Di Maio et al., 2017).

B-4 Key and extended functionalities of the discussed logistic information systems

In this appendix elaborate information is provided over the logistic information systems discussed in Chapter 5.

Enterprise Resource Planning (ERP)

An ERP system can be considered as a tool that enables comprehensive planning, coordination and management of the different functions within an organisation (Nettsträter et al., 2015; Cheng et al., 2010). ERP systems offer tools to assist internal company processes covering finance, accounting, manufacturing or controlling (Nettsträter et al., 2015). In addition, the system enables information sharing within the company internally. An elaborate list of key and extended functions of ERP systems is provided by Nettsträter et al. (2015), see Figure B-1.

As business processes are dynamic, it is important for these systems to be able to adapt, however they currently lack this flexibility. In addition, Cheng et al. (2010) argues that other limitations are namely: absence of modular and open technical standards, low efficiency in sharing information with other supply chain stakeholders, and limited to financial transactions.

Figure B-1: Key and extended functionality of typical ERP systems (adapted from Nettsträter et al., 2015, p.3

Transportation Management Systems (TMS)

Transport Management Systems were developed to aid logistical distributors when dealing with increased complexity within transport chains of products/materials. TMS systems focus in providing planning, control, monitoring and optimisation of complex distributions (Nettsträter et al., 2015). The optimisation functionality cover beside product distribution structures also the optimisation of procurement structures, by considering control and monitoring of finance, time and planning of multi-modal transport chains. According to Whitlock et al. (2018) these systems store information on the properties of transportation, such as physical specifications of the products, origin, destination and duration of deliveries. An overview of key and extended functionalities of TMS systems is provided in Figure B-2.

The complexity of transport management systems usually lies at the introduction of multi-modal structures of transportation. In recent years, this is a highly required functionality; however, there are limitations to this as multi-modal structure will require the alignment of schedules and plans for different transport chains.

Figure B-2: Key and extended functionality of typical TMS systems (adapted from Nettsträter et al., 2015, p.6

Warehouse Management Systems (WMS)

Warehouse Management Systems focus in providing control and monitoring in the inventory and movement of the products/materials stored in warehouses, by also processing associated transactions (Ramaa et al., 2012). The primary purpose of WMS systems is to have an overview on the inventory and movements that lie withing a company's storage (Nettsträter et al., 2015). To control such movements there is a need for the software to have optimisation functionalities that will result in cost-efficiency foe the warehouses and suppliers. As a consequence, WMS systems encapsulate functionalities that are connected to ERP or TMS systems to overview all the processes from ordering to delivering specific products and goods (Nettsträter et al., 2015). In addition, some specific functionalities of WMS systems, regard route plannings, inventory management, billing support and other value adding services that deal with multi-client scenarios. An overview of additional functions of such systems is provided in Figure B-3.

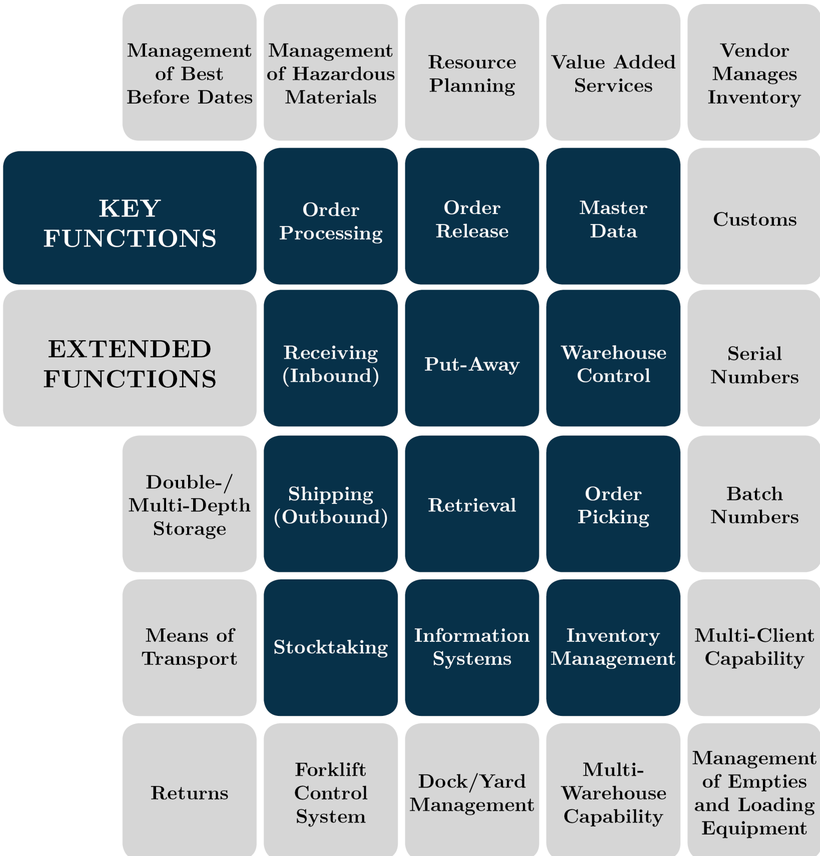

Figure B-3: Key and extended functionality of typical WMS systems (adapted from Nettsträter et al., 2015, p.5

Advanced Planning Systems (APS)

Advanced Planning Systems were developed to address the limitations that the ERP systems face, specifically related to planning limitations. According to Stadlter et al. (2015), APS systems assist the creation of integral, optimised and hierarchical planning structures. The system oversees the planning activities of the supply chain, while optimisation is achieved *by properly defining alternatives, objectives, and constraints for the various planning problems and by using optimising planning methods, either exact ones or heuristics* (Stadtler et al., 2015, p. 74). These two characteristics comprise the so-called hierarchical planning, which allows to establish inter-dependencies between the different planning activities. APS systems can be seen as the integration of different functions of ERP systems by providing an overarching planning system for the supply chain. However, there are two main limitations addressed: (i) lack of real-time information and (ii) no direct link to a company's cost accounting system (Stadtler, 2005). This information system is mainly associated with the internal integration of individual organisations and little is done across company borders (Stadtler, 2005).

Glossary

List of Acronyms

APS	Advanced Planning Systems
BCI	Building Circularity Index
BIM	Building Information Modelling
CBA	Circular Building Assessment
CE	Circular Economy
CEI	Circular Economy Index
CTI	Circulair IQ transition indicators
CLD	Closing the Loop by Design
CSC	Circular Supply Chain
ECR	Eco-Cost Value Ratio
ERP	Enterprise Resource Planning
GIS	Geographical Information Systems
LCA	Life Cycle Assessment
MBE	Management in the Built Environment
MCI	Material Circularity Indicator
MCSCM	Modular Circular Supply Chain Model
MFA	Material Flow Assessment
MRS	Material Reutilization Score
PLCM	Product Level Circularity Metric
RI	Recycling Index
RSC	Reverse Supply Chain
SCM	Supply Chain Management
TMS	Transportation Management Systems
VRE	Value-based Resource Efficiency Indicator
WMS	Warehouse Management Systems