Closing the Loop

A Decision Support Framework for Circular Economy implementation to the adaptive reuse of buildings in the Netherlands

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Preface

When I enrolled at TU Delft, I had a wide range of expectations. The boundaries of that range were as blurred as my understanding of the Dutch culture and language. I did, however, have a notion what I would gain during my Master's degree: the fundamental tools for managing the built environment at different levels, and a deeper understanding of the dynamics that drive and regulate it. This was the knowledge gap I wanted to fill. I found more. I found in the Dutch built environment the possibility of a system congruent with the needs and goals of human beings and the environment. Looking at the practical world in the Netherlands, I found huge potential for sustainability.

To begin with, I intuitively thought that the adaptive reuse of vacant buildings into housing was a resilient way to tackle social and environmental problems. At first, it seemed like a disruptive idea, but over time I came to realise it was actually based in more long-standing ideas about urban development: adaptive reuse plays a significant role in the evolution of a sustainable built environment. It is an important element of the transition towards a Circular Economy (CE); it enriches societies, preserves resources for future generations, and suggests different "end-of-use" options for buildings.

Diving into this topic, I found it to be an emerging field still struggling to fully deliver environmental benefits. In examining the practical world, I realised that symbolic work also needed to be done to show how fully circular adaptive reuse can be achieved. However, I did come to wonder how this can be done if, in practice, organisations usually only consider the benefits to themselves, and if the CE literature is largely focused on the macro and meso systemic level and is not refined enough to analyse individual buildings. If there are no benefits for those taking the risks and no guidelines for implementing this change, then nothing can be done. As financial aspects should not be the only criteria to measure the performance of a project I decided to look at the field of business models or business processes (the rationale behind generating value), and try to understand how applying CE principles in the value chain can help a resilient idea (adaptive reuse) fully deliver environmental benefits, value for society, and value capture to continue along the road towards a better future for the built environment. I hope my written text tells a good story about buildings, that, through their life cycles, we can find a sustainable future for humanity.

Christian Lesmes Mendoza
Rotterdam, June 23, 2020

Abstract

The Circular Economy (CE) in the built environment has gained ever more attention as discussions around the threats of global warming, resource scarcity, environmental impacts, and energy emissions intensify. The building industry accounts for approximately 40% of carbon emissions and reusing vacant buildings – thus slowing resource loops – is one of the strategies on offer to address this. However, research shows that the adaptive reuse of vacant buildings also contributes to their embodied emissions if the process is not fully aligned with CE principles. In addition, the CE is often conceived of as a binary outcome: either projects are fully circular or not circular at all. Identifying how far a project still has to go to become fully circular is an essential step in closing this gap, but how can this be done?

This research contains an examination of the processes which are considered to be of importance at the inception of a project. In it, the results of two case studies, exploratory interviews with experts, and a literature review are used to design a decision support framework (DSF) to support decision makers in housing associations in pursuing greater self-sustainability in their assets. This research also includes an exploration of existing, complementary CE methodologies, and an illustration of how they can be applied to adaptive reuse projects. This involves an examination of the complexity of these CE methodologies, and the delivery of a series of practical steps to achieving a low, medium or high degree of circularity. Using the DSF, an evaluation of a circular project in the Netherlands is then carried out, and recommendations and a step-by-step plan for achieving a completely circular project are set out.

Key words - Circular economy, adaptive reuse, housing associations, housing, sustainability.

Contents

01

Introduction

1.Introduction

1.1. The Circular Economy

The CE is viewed as a promising approach to achieving sustainability targets (Bocken, de Pauw, Bakker, & van der Grinten, 2016), and is particularly important as a global future strategy. It is a powerful approach that presents new opportunities for real estate businesses to touch customers, eliminating costs through reverse cycles, and creating new relationships with suppliers. Some notions of circularity are already being implemented in the built environment, including the adaptive reuse of buildings. This activity extends the lifespan of buildings by preventing them from being demolished prematurely, and reducing embodied and operational carbon emissions and energy consumption throughout their lifecycle (Foster, 2020). Previous studies discuss the opportunities and risks of the adaptive reuse of office spaces into housing, and how, with suitable vacant buildings, it can be a feasible option for investors and developers (H. Remøy & van der Voordt, 2014). For example, in the Netherlands, the adaptive reuse of vacant offices has progressed at a rapid pace in exceptionally high-rent residential cases in cities like Amsterdam and the Hague (CBRE, 2018), where residential income outstrips revenue gained from office investments.

However, the adaptive reuse of office buildings into housing does not guarantee that environmental benefits are fully delivered. Adaptation usually still requires the implementation and disposal of resources, and the act of adapting for reuse can therefore add significantly to the embodied emissions of existing buildings (Ibn-Mohammed et al., 2013), diminishing the environmental benefits of adaptive reuse, and limiting the possibility of achieving a fully CE in the building industry. In addition, adaptive reuse is often seen as a more expensive option by potential investors who would usually opt for demolishing and building anew (Foster, 2020). However, the decision to demolish may be premature if it ignores the residual value and utility of buildings that can be optimised by refurbishment and reuse (Bullen & Love, 2011).

One solution to these problems is to fully implement CE principles in the adaptive reuse process. This means rethinking how the material transactions, organisational structure, and roles within the adaptive reuse life cycle are managed in order to reduce waste, extend the lifespan of resources, recycle material, and capture value. It means rethinking entire networks of production and the responsibilities spread across these networks, considering the provider and user as not ethically neutral (Murray, Skene, & Haynes, 2017). To do this, organisations involved in adaptive reuse need to identify where modifications can be made in the production network, and to what degree, creating value for society and the organisation through circular and clean[1] buildings.

Previous research shows that scholars in the strategic management field are struggling with the lack of a framework explaining how companies can implement CE principles in their business rationale (Urbinati, Chiaroni, & Chiesa, 2017). This is because there are very few works of literature that indicate how and to what degree a single firm's business processes can be aligned towards the CE (Urbinati et al., 2017). In order to achieve a self-sustaining economy, true circularity at the level of the building is needed (Saidani, Yannou, Leroy, & Cluzel, 2017). Empirical research on specific micro- and nano-level[2] cases needs to be carried out to

[1] In the EU, a product is 'clean' when the average Eco cost per euro spent (EVR) is 0.4. When the average is higher, it is considered a 'dirty' product (A. Scheepens, J. Vogtländer, & J. Brezet, 2016a).

[2] CE is usually performed at three systemic levels. "Macro" refers to city, province, region and nation, "meso" encompasses eco industrial parks, and "micro" corresponds to single company consumers. Some authors propose a fourth level related to the CE of the product, components, and materials included in the three wider systemic levels throughout the value chain and lifecycle (Saidani et al., 2017).

understand how the business processes of creating a building can include CE principles. Using a case study, this research focuses on how, and to what degree, a business model (BM) based on CE principles can be applied to the adaptive reuse of office buildings. Through exploratory interviews and an examination of the key factors identified in the case study, this research provides a decision support framework (DSF) for developers to integrate their CE targets into their BMs.

1.2. Research aim

The adaptive reuse of vacant buildings pursues CE practices in the built environment but does not currently deliver a fully circular building. This research examines the implementation of CE principles in the adaptive reuse value chain, and uses a DSF to explore the distance still left to travel if we are to achieve a fully circular project. Previous studies show the difficulties of implementing and measuring the performance of CE principles in single firms and products, as there is little knowledge of how, and to what extent, this can be achieved at these levels (as CE research is mainly focused on how it can be achieved at the macro level). This research therefore aims to answer the following question:

1.2.1. Main question

How can CE principles be applied in the business model for the adaptive reuse of office buildings into housing?

To answer this question, the following sub-questions also need to be considered. These questions are classified into three different types according to the issues they address in this research: (1) definition, (2) validation, and (3) conclusion.

1.2.2. Sub-questions:

Definition (Theory)

What practices based on CE principles can be applied by housing investors in the adaptive reuse of office buildings?

What do the different business model components of a circular adaptive reuse project look like?

Validation (Practice)

Where, and to what degree, is circularity applied to the business model components of the adaptive reuse case study project?

What are the key elements in the success of the circular business model?

Conclusion

What does a decision support framework for housing investors to implement CE principles to the business model look like?

1.2.3. Conceptual model

The following conceptual model is based on the main research question (Figure 1). At the centre of the model is a DSF built up of theoretical CE and BM principles. These principles form the backbone of this research and support the definition of a theoretical DSF. The case studies are investigated to determine the degree of circularity applied in their BM components. This will help validate the suggested DSF and operationalise it for decision making. Finally, findings and recommendations for adaptive reuse will be defined through three BM options.

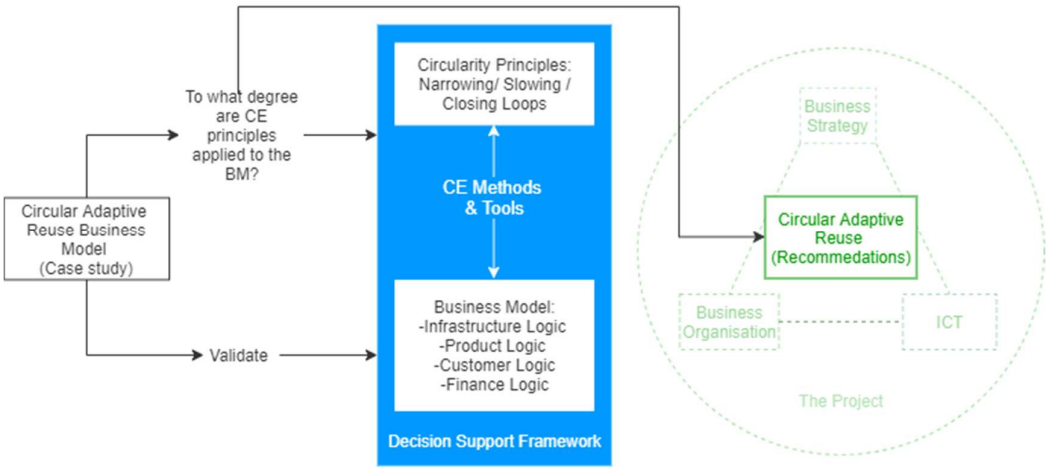

Figure 1. Conceptual model (own work) based on principles found in the literature (Bocken et al., 2016; Linder, 2000; Lüdeke-Freund, Freudenreich, Schaltegger, Saviuc, & Stock, 2017; Osterwalder, Pigneur, & Tucci, 2005).

1.2.4. Deliverables, dissemination, and audiences

The conceptual model depicted in the image above defines two main outputs. First, a DSF draft is defined and structured within the principles of this research and then validated using a case study. This research delivers a DSF to implement CE principles in the BM for adaptive reuse into housing. Recommendations and findings to build up a business model for a circular adaptive reuse project are then described.

This research is directed mainly towards housing corporations in the Netherlands that are interested in optimising and aligning their adaptive reuse projects towards a CE. This research points specifically to housing corporations' BMs for the adaptive reuse of office buildings. Previous studies show that housing corporations and housing investors in the Netherlands are interested in the adaptive reuse of vacant offices into housing. This is because housing investors and housing corporations are organisations that usually expect revenues in the long term (Remøy, 2010). These organisations are mostly focused on housing development in inner-city areas, which leaves them two alternatives: to redevelop or transform vacant properties, hopefully in a circular way.

1.3. Relevance

1.3.1. Scientific relevance

This research should fill a gap in the field of management in the built environment by using the BM field as a resource to shine a light on CE implementation. As mentioned in the problem statement above, the adaptive reuse of offices is a feasible activity when suitable parameters concerning the building and its location are met (Remøy, 2010). Adaptive reuse has also increased in recent years in the Netherlands (CBS, 2019a). The adaptive reuse of office buildings is proven to diminish carbon emissions and foster sustainability and CE goals (Foster, 2020), but previous research also indicates that it can add significantly to embodied emissions (Ibn-Mohammed et al., 2013), and that developers perceive it as more expensive than demolishing and building anew (Foster, 2020).

These caveats can be addressed by implementing CE principles in the adaptive reuse process. However, research indicates that scholars in the CE field struggle to do so at the micro-level, and specifically at the level of building components, because of the lack of CE guidelines.

In addition, it is unclear how far we are from achieving a self-sustaining economy at the building level, as literature on the CE tends to refer to macro-level solutions. Empirical research focused on single firms and product components is therefore needed to provide broader knowledge on how the CE can be implemented in practice, to what degree, and how this can impact capturing value within the firm. To do so, the BM field is helpful, as it provides knowledge on the business logic of adaptive reuse. Finally, the outcome of this research will add to the body of knowledge on CE implementation at a building component layer, and will provide a tool for the strategic management field to align the adaptive reuse business logic to the CE.

1.3.2. Societal relevance

The general objective of this study is to promote the implementation of circular strategies and adaptive reuse in the built environment. This *per se* delivers social and environmental benefits. Defining a DSF that enables the implementation of a CE at the micro level is the starting point for pursuing this new paradigm at the meso and macro levels. With the output of this research, organisations in the built environment should be able to use a DSF to improve their decision making towards the CE.

02

Literature Review

2.Literature Review

2.1. Business models

2.1.1. Business model development and the built environment

In the built environment, organisations should not see financial criteria as the only aspect to consider when measuring a building´s performance. If real estate investors understand this, they might avoid overinvesting in short-term financial results and underinvesting in long-term value creation. Winch's (2009) argument consists of four added value-investment areas: financial value, indoor environmental quality, spatial quality and symbolic quality. These four areas are where investing above or over the regulations of minimum functional standards can be added in order to improve business processes' effectiveness and efficiency. The four areas were first developed based on Kaplan's (2005) balanced scorecard.

The CE can be considered within these four areas, adding value to constructed assets. For instance, when primary resources become scarce, investing in CE principles enables investors to position their projects or project layers in a volatile material price market. Symbolically embracing CE as a branding strategy, and managing material and people flows in an efficient and effective way through customisation and other CE principles are other examples of areas for investment. But where exactly should the investment go to?

CE has to be included in the definition of the project mission. The following types of business processes, defined by Winch (2009), are key subjects:

- Information flow
- Financial resource flow
- Material flow
- People flow

These processes are spatial and non-spatial. The information process is related to information flows through communication systems, or are embodied in people and therefore can be a type of people flow. Financial resources are not spatial either, but refer to revenues and costs accounting processes. Material and people are consumers of space and require movement. In the case of materials, they travel through a specific infrastructure and people can flow by themselves through transport infrastructure.

In general, CE business processes aim to establish adequate information flows that enable material efficiency and effectiveness, exploring different ways of interaction with users and proposing diverse financial methods. Therefore, CE must be considered in the business processes of the organisation involved in real estate development. One way of analysing the business process is by using the well-known business model concept.

The term business model (BM) is relatively young: it only emerged as an explicitly defined notion 15 years ago (Lüdeke-Freund, Freudenreich, Schaltegger, Saviuc, & Stock, 2017). Previous studies indicate a relationship between the widespread appearance of the term BM and the increasing popularity of the internet and information technology (IT) systems through the 2000s, as well as the appearance of the personal computer and the spreadsheet (Magretta, 2002). This indicates that BM gained importance when cheap information, bandwidth, and communication possibilities made transaction costs fall significantly (Osterwalder, Pigneur, & Tucci, 2005), and the internet offered managers greater business design choices. As a consequence, industry boundaries became blurred (Osterwalder et al., 2005) and the BM became the perfect candidate to replace the industry as a unit of analysis (Osterwalder et al., 2005).

BMs are a useful tool for managers to align their business organisations, business strategies, and innovative IT systems (Chesbrough, Rosenbloom, & change, 2002); they are units of analysis and a representation of the business rationale, where strategic actions can be based. As BMs are considered the foundations of further strategic management and decision making, this research studies how to define a circular business model (CBM) for the adaptive reuse of office buildings, exploring how the logic of the entire adaptive reuse production network is adopting CE principles in practice.

2.1.2. Business Model concept

Creating a BM is like writing a new story out of old ones, as variations; a reconstruction of the universal themes underlying all human experience (Magretta, 2002). In this research, various definitions and literature related to BMs were reviewed. A broad definition is:

"A business model is a conceptual tool that contains a set of elements and their relationships and allows expressing the business logic of a firm. It is a description of the value a company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing and delivering this value and relationship capital, to generate profitable and sustainable revenue streams" (Osterwalder et al., 2005).

Or this quote taken from Winch (2009) can help define business processes.

"This is clear from Thomas Davenport's formulation of a business process as 'a specific ordering of work activities across time and place, with a beginning, and end, and clearly identified inputs and outputs: a structure for action" (Winch, 2009).

Table 1. Summary of literature on BM (own work)

Author	BM concept	BM frameworks	BM & strategy
(Magretta, 2002)	●		
(Chesbrough et al., 2002)	●		
(Linder, 2000)	●		
(Applegate, Austin, & McFarlan, 2006)	●		●
(Weill & Vitale, 2001)	●	●	
(Osterwalder, 2004))	●	●	
(Urbinati et al., 2017)		●	
(Seddon & Lewis, 2003)	●		
(Porter, Michael, & Gibbs, 2001)			●
(Mintzberg & Lampel, 1999)			●
(Henderson & Venkatraman, 1999)			●
(Ballon, 2007)	●	●	
(Anne van Stijn, 2019)		●	
(Kaplan & Norton, 2005)			●
(Winch, 2009)	●	●	●

The BM is an abstract representation of an aspect of a strategy. It differs from a strategy because it does not involve the concept of competition. A strategy involves a company's long-term

position in the marketplace (Porter et al., 2001); a BM describes how the pieces of a business fit together (Magretta, 2002). BMs are the patterns from which strategies can be built. They are the blueprint of a strategy, or the rationale of how a firm makes money, translated into units of analysis. BMs can be built before the real system to help predict how the system might respond if we change the structure, relationships, and assumptions (Applegate et al., 2006). They can also be used to assess an existing system.

2.1.3. Sustainable business models

In the literature, the concept of the sustainable business model (SBM) is found both within the BM field and as a stand-alone field. Recent research sees it as an integrated field that depends on, but goes beyond, the BM. It is therefore a useful vehicle for achieving sustainable businesses (Lüdeke-Freund & Dembek, 2017). The sustainability concept can be defined as "the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations" (Geissdoerfer, Savaget, Bocken, & Hultink, 2017), and is understood in this research as the ideal stage for a BM to pursue sustainability goals. Circular business models (CBMs), the focus of this research, are therefore a means of achieving an SBM. CBMs are defined in this research not as a field in and of itself, but as a subset of the SBM field, as shown in the Venn diagram below (Figure 2). Therefore, this research does not explore the social impacts of CBM implementation, but rather focuses on three circularity principles: slowing, narrowing, and closing resource loops. These principles will be defined further in Section 2.2.3.

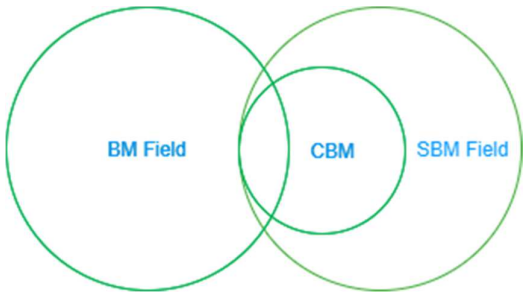

Figure 2. Allocating the CBM within the SBM field (own work).

2.1.4. Business model canvas

The nine building blocks suggested by Osterwalder form the framework of this research. This well-known BM canvas establishes a framework to develop a detailed analysis of a firm's BM or, in the case of this research, of a BM for an adaptive reuse project. The framework is comprised of nine units arranged in four main pillars: infrastructure management, product, customer interface, and financial aspects.

Osterwalder compares these pillars to those defined in Kapan & Norton's Balanced Scorecard (Kaplan & Norton, 2005), which suggests four perspectives to consider in order to conduct successful businesses: internal, customer, innovation and learning, and financial.

Delving deeper into a more detailed perspective, Osterwalder (2004) defines nine blocks within the four pillars. These blocks or elements are joined to each other through a set of sub-elements (Figure 3).

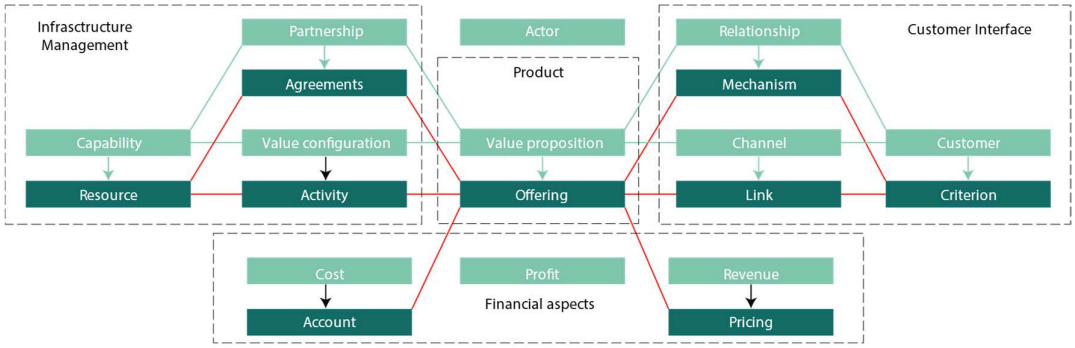

Figure 3.Relation between main pillars, elements and sub-elements (Osterwalder, 2004)

Each of the building blocks, or business elements, is arranged as shown in Figure *4*. Elements are separated out into sub-elements to allow a higher level of detail if needed. In that case, the element can be separated into a 'set of' sub-elements which inherit their properties. The description of each element can be found in the Table 2.

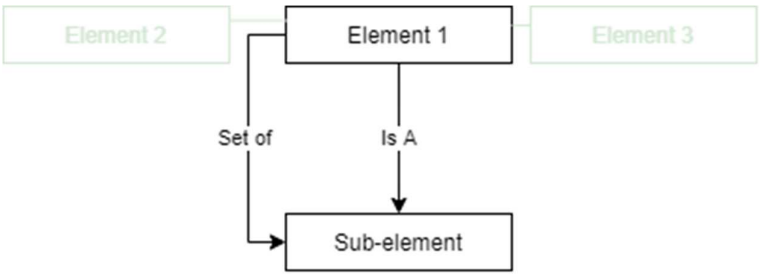

Figure 4 Graphical representation of element and sub-element.

Table 2. Osterwalder (2004) BM canvas overview.

Four pillars	Element	Description	Sub-element	Description
Infrastructure management How the company efficiently performs infrastructure and logistical issues, with whom, and as what kind of network.	**Partnerships**	A voluntary cooperative agreement between two or more companies to create value for customers. Partnerships are a set of **agreements**.	**Agreement**	**Agreements** are the terms and conditions of a partnership with an actor.
	Capabilities	The ability to execute repeatedly the pattern of actions necessary to create value for a customer. Capabilities are a set of **resources**.	**Resource**	**Resources** can be tangible, intangible, and human.
	Value configuration	The arrangement of activities and resources that are necessary to create a value proposition. It is mainly a set of **activities**.	**Activities**	**Activities** are the heart of value creation. They are actions companies perform to do business and achieve goals.
Product What business the company is in, the products, and the value propositions offered to the market.	**Value proposition**	Value for target customers, based on capabilities. The value proposition is a set of **offerings**.	**Offerings**	**Offerings** can have a description, a reasoning (i.e. effort reduction), a value level (i.e. utility), a price level (i.e. high end), and a life cycle (i.e. renewal).
Customer interface Who the company's targets are, how it delivers products and services, and how it builds a relationship with them.	**Distribution channel**	How a company delivers a value proposition to a target customer segment. How a company gets in touch with customers. Channels create **links** between the company and the customer.	**Links**	**Links** describe a specific channel role. As offerings, they can reduce risk, effort or have a use. To reveal the role of the links a customer life cycle analysis needs to be carried out.
	Relationship management	Describes the relationship a company establishes with a target customer segment. It is based on customer equity and is a set of relationship **mechanisms.**	**Mechanisms**	**Mechanisms** describe the function the relationship accomplishes between the company and its customers (i.e. customisation or trust).
	Target customer	Defines the type of customer the company wants to address. It is a set of **criterions**.	**Criterions**	**Criterions** define characteristics of target customers.
Financial Aspects The revenue model, cost structure, and business model's sustainability	**Cost structure**	Measures all monetary costs incurred by the company. It is an **account**.	**Account**	An **account** is a registry of transactions (expenses) of a certain category.
	Revenue framework	The way companies make profit. It can be composed of one or several **revenue streams** and **pricing elements.**	**Revenue streams**	**Revenue streams and pricing methods** describe the incoming money for the value offered by the company, and what mechanism is used to determine the price of the value offered. A stream type is an economic activity (i.e. lending, selling, advertising.). A pricing method can be fixed (i.e. pay per use), differential (i.e. based on customer) or market oriented.

2.2. Circular economy

The circular economy (CE) is not a new topic. It has been theorised since 1990 in the field of industrial ecology (IE) as an analogue biological ecosystem for the industry (Bocken et al., 2016). This concept is now a public concept and part of public policy in some countries at different systemic levels: macro, meso and micro, as explained in Chapter 1. Circularity can be described according to three main principles (A. van Stijn & Gruis, 2019): (1) Preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows. (2) Optimising resource yields by circulating products, components, and materials at their highest utility and value at all times in both technical and biological loops. (3) Fostering system effectiveness by revealing and designing out negative externalities. The CE is a regenerative system in which resource inputs and waste, emissions, and energy leakage are minimised by slowing, narrowing, and closing loops (Lüdeke-Freund, Gold, & Bocken, 2019).

2.2.1. Circularity development as a subset of sustainability

When first developed as a field in the early 1990s, IE referred to an industrial ecosystem that can work as a biological ecosystem where materials are reused, recycled, and optimised by nature. The concept of the CE has since been (re)popularised as a business concept and part of public policies, where it has been adopted by governments and institutions at the macro, meso, and micro levels (Lüdeke-Freund et al., 2019; Anne van Stijn, 2019).

CE is a "regenerative system in which resource input and waste, emissions, 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, remanufacturing, refurbishing, and recycling" (Geissdoerfer et al., 2017, pg. 766, pg. 766). This research therefore explores the influence of *slowing the loops, narrowing the loops, and closing the resource loops* (Bocken et al., 2016) over the performance of the different components of the BM for the adaptive reuse project.

2.2.2. Circularity development in the built environment

Buildings consume 44% of natural resources globally, produce 40% of global waste, and release 33% of emissions (Ness & Xing, 2017; A. van Stijn & Gruis, 2019). Resources in the built environment (and most other industries) are extracted, used, and turned into waste according to a linear (non-circular) BM, and this is becoming unsustainable due to resource scarcity. Circular BMs in the built environment are therefore an important factor in building a sustainable industry and society. CBMs are directed to achieving the following three principles of the CE:

1) Decoupling economic growth from resource consumption, thus becoming an alternative to linear (non-circular) activities.
2) Allowing for the optimisation of resource yields by circulating materials, products, and components at their highest utility and value at all times, both in biological and technical loops.
3) Aiming for effective systems by revealing and designing out negative externalities (A. van Stijn & Gruis, 2019).

These three principles refer again to the CE principles that form the backbone of this research: slowing, narrowing and closing the resource loops. The operation of these three principles was explored in the built environment field (Bocken et al., 2016) even before the term 'circularity' appeared. Seven different applications to a building's lifecycle that reverse resource flows that close, narrow, or slow loops can be identified in these initiatives. They are: (1) repair and maintain, (2) reuse and distribution, (3) refurbishment and remanufacturing, (4) recycling, (5) cascading and repurposing, (6) biochemical feedstock extraction, and (7) austere products (products made with the least possible material).

2.2.3. Circularity principles

Slowing resource loops can be done through the design of long-life goods and extending a product's life. Closing resource loops can be achieved by recycling, closing the loop between post-use and production (Bocken et al., 2016). Narrowing the resource flows aims to reduce the use of resources in the production of new products.

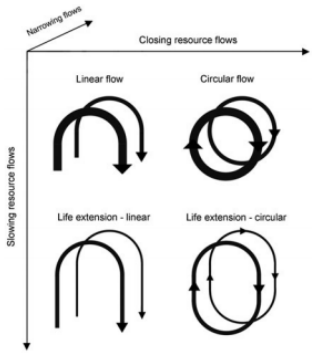

Figure 5. Three CE principles: Close, slow and narrow material loops. (Bocken et al., 2016).

Figure 5 shows how, by implementing the three CE principles, loops can be closed and a transition from a linear flow to a circular flow can be achieved. Slowing the loops extends the life of that flow, and narrowing them makes them 'thinner,' with less material involved. The concept of degree of CE is also introduced; achieving the three principles produces a total circularity output, but a lower degree of CE can be achieved by implementing two or one of the principles.

The literature mentions different strategies that could be implemented to complete any, part, or all of the CE principles. Some authors and their strategies are classified in Table 3 below.

Table 3. Reverse cycles in literature.

W.Stahel 1976	Boecken et al.2016	Potting et al. (2017) & Vermeulen (2014)	Freund et al. (2019), EMF (2012).	Mckinsey, 2016
Closing material loops	Narrowing Loops	• Refuse • Rethink • Reduce		• Share • Optimise • Virtualise • Exchange
	Slow loops	• Reuse • Repair • Refurbish • Remanufacture • Repurpose	• Refurbish • Manufacture • Cascading & Repurposing • Reuse & Distribution	• Loop
	Closing loops	• Recycle • Recover	• Recycling • Biochemical Feedstock	• Regenerate • Loop

These principles are based on Stahel's (1976) main idea of closing the material loops using the concept of 'cradle to cradle.' With this as a starting point, the Ellen Mac Arthur Foundation (2012) explored six main reverse cycles to close material cycles (Figure 6).

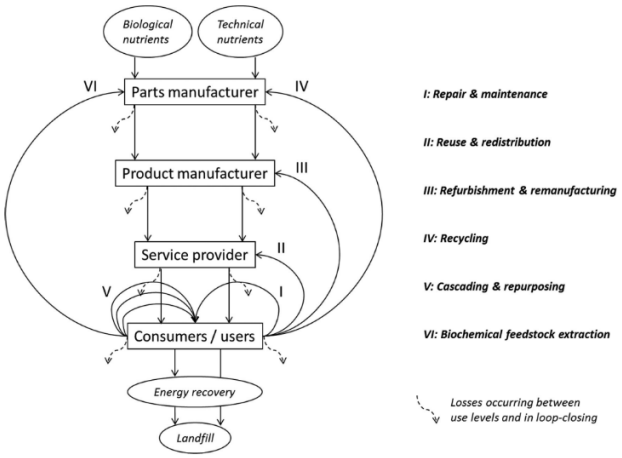

Figure 6. Six major cycles by EMF (2012)

Mckinsey & Company (2016) developed ReSolve, a circularity framework which added strategies to narrow loops (Table 3). The latter complemented the reverse cycles and added new possibilities like sharing, optimising, and virtualising.

Potting et al. developed a 9R model or strategies based on Ladder van Lansik (1979) and Vermoulen (2014) to close loops, focusing on a priority plan for waste treatment (Potting, Hekkert, Worrell, & Hanemaaijer, 2017). The 9R strategies can be allocated in three main strategies suggested by the model, illustrated below (Figure 7). It suggests a nine-tiered strategy ladder and establishes the implications of these levels for achieving circularity.

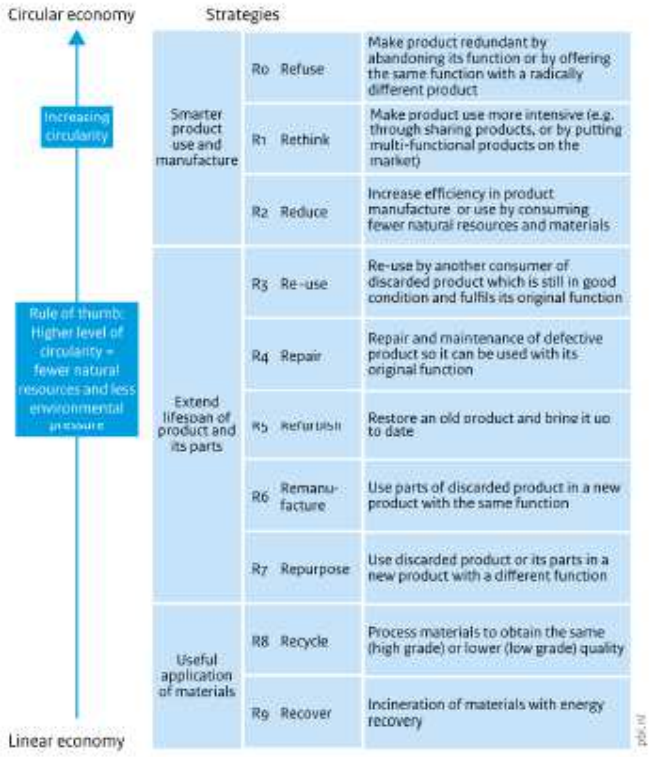

Figure 7. Circular strategies within the production chain (Potting et al., 2017).

The model classifies strategies from low circularity (high R number) to high circularity (low R number). R0 to R2 are strategies that aim to limit the direct extraction of primary resources and can be understood as strategies for narrowing loops, R3 to R7 aim to slow the loops, and R8 and R9 aim to close the loops. In the model, these strategies are grouped within three main strategies. Stijn and Gruis (2019) relate these three strategies with Boecken's (2016) three CE principles, which are those used in this research.

All these strategies must be executed in an integrated way to achieve circularity. Therefore, following Boecken's (2016) model, in this study a high degree of circularity is defined as the achievement of closing, slowing, and narrowing the loops. If only two principles are achieved, then a medium degree of circularity is observed. If only one principle it is achieved, then there is a low degree of circularity.

2.2.4. CE methodologies and tools

In order to evaluate, monitor, or ensure the degree to which CE principles are being implemented in a system, effective methodologies and tools are needed. CE methodologies from different disciplines like industrial ecology have been discussed in the built industry field. CE evaluative methodologies are directed towards closing material loops throughout the project lifecycle. They can be standardised and non-standardised, and impact different areas in the CE value chain. As an expert in CE renovations pointed out,

> "In the CE project I think it's important to have the MFA material flow analysis. But actually, you should always combine it with an LCA because a material flow analysis on its own, doesn't say that much. it's one side of the coin, but the other side is equally important. Same question applies to the last one."

Table 4 shows the different authors that discuss CE methodologies, and how these are directed towards the real estate production process. In this research, is important to at least review two or more authors related to each method.

Table 4. Summary literature about CE methodologies (Own work

Author	Project M.	Material Flow Analysis	Material Circularity Index	Design for X	Life Cycle Analysis	CE Promotion	Customisation	Life Cycle Cost	Product Service Systems
(Versteeg Conlledo, 2019),	●								
(Arnette, Brewer, & Choal, 2014; Mayyas, Qattawi, Omar, Shan, & Reviews, 2012)				●			●		
(EMF; Graedel, 2019)		●	●		●				
(A. Scheepens, J. Vogtländer, & J. J. J. o. C. P. Brezet, 2016b)					●				●
(Chiaroni & Urbinati, 2016)				●		●	●		●
(Boulding, Lee, & Staelin, 1994)						●			
(Arup & EMF, 2020)		●	●	●	●		●		●
(Norris, 2001)					●			●	
(Tukker, 2004)							●		●
(Rijkswaterstaat, 2015)			●		●			●	
(van den Berg, 2019)	●	●		●	●				
(Saidani et al., 2017)			●						

2.2.4.1. Project management body of knowledge

Different authors have studied how to manage projects in the built environment within the CE. Some of them suggest that the CE starts with the development of a common vision and the importance of the requirements established by the client (Leising, Quist, & Bocken, 2018). Other studies focus on the information flow and its efficiency and organisation using Building Information Modelling (BIM) tools during the process. M. Venselaar (2019) concludes that to implement CE, the project management (PM) should be able to bring expertise form elsewhere to the project, and that CE requires that there be space in the management process to experiment for the development of new capabilities. Thus, circularity is an extra ambition used within the same manner of thinking about PM. In the same vein, Ana Versteeg (2019) looks at three well-known methods in construction projects: Prince 2, Projectmatig werken, and PMBoK. PMBok focuses on the processes and product, while Prince2 is oriented more towards the product. Projectmatig werken is similar to the latter and implements in a more local way in the Netherlands. PMBoK was chosen in this research because it covers elements of both of the other methods (Versteeg Conlledo, 2019).

PMBoK is a set of best practices. It does not suggest methodologies or tools. Therefore, more than being a prescriptive methodology, it is a framework built up of ten elements, to which Versteeg (2019) added two: “Project Health, Safety, Security and Environmental management

(HSSE) and Project Financial Management (Project Management Institute, 2016)" (Versteeg Conlledo, 2019). The 10 elements are described in Figure 8 below.

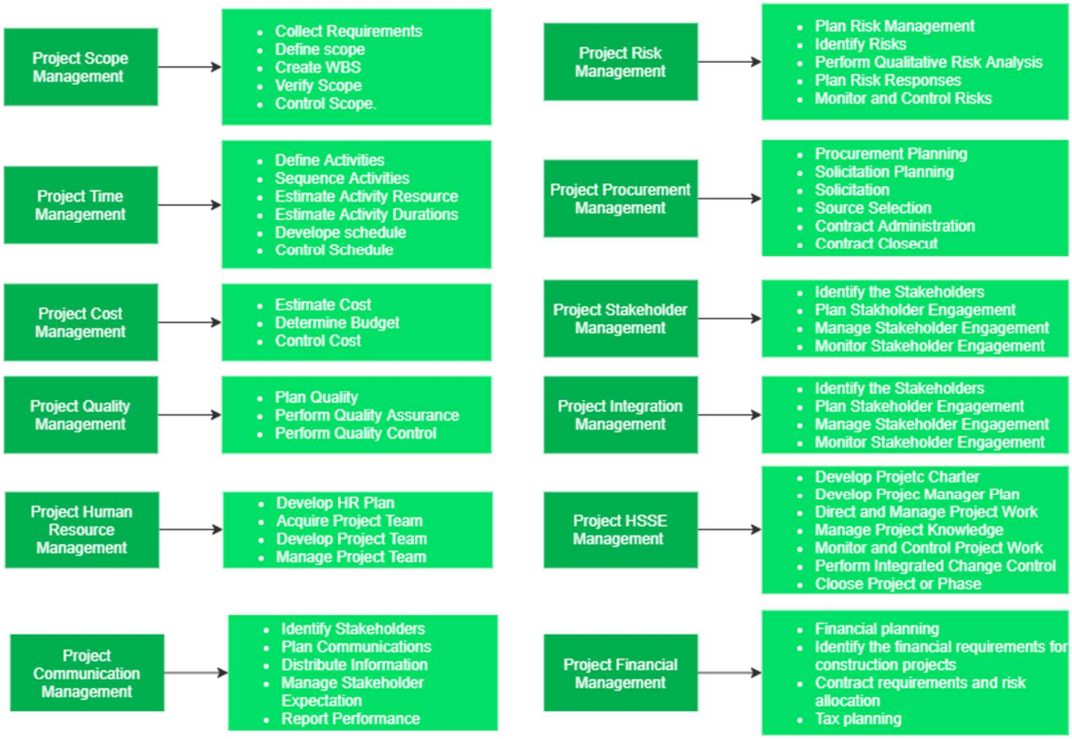

Figure 8. CE-PMBoK framework (Versteeg Conlledo, 2019).

This research considers the six PMBoK elements that need to change for CE to be achieved in a project's management according to Versteeg Conlledo (2019) (Table 5).

Table 5 PMBoK topics needed for the CE (Versteeg Conlledo, 2019).

PMBoK topic	Features
Project scope management	Define CE ambitions Define requirements with project team
Project cost management	Open budget in a transparent way for the team
Project human resource management	Search for team members with the same circular commitment vision and philosophy
Project Procurement management	Plan tender process early in the project and involve service suppliers early in the project Build contracts that ensure CE principles
Project integration management	Establish non-hierarchical and cooperative structures Ensure project knowledge is shared in a transparent way
Project financial management	Responsibilities and risks shared between the parties

2.2.4.2. Material Flow Analysis

Material Flow Analysis (MFA) has been a central methodology for industrial ecology since the beginning of this century. The main aim of MFA is to map and quantify material resources: biomass, polymers, minerals, and the waste and emissions of a system. It is a specialised methodology that (1) studies a design material flow system, (2) defines a detailed description of each flow in the system, (3) establishes a quantitative significance in the system and

conservation of mass applied at each node, and (4) the output of the analysis is diagrammatic and numeric represented in a Sankey diagram.

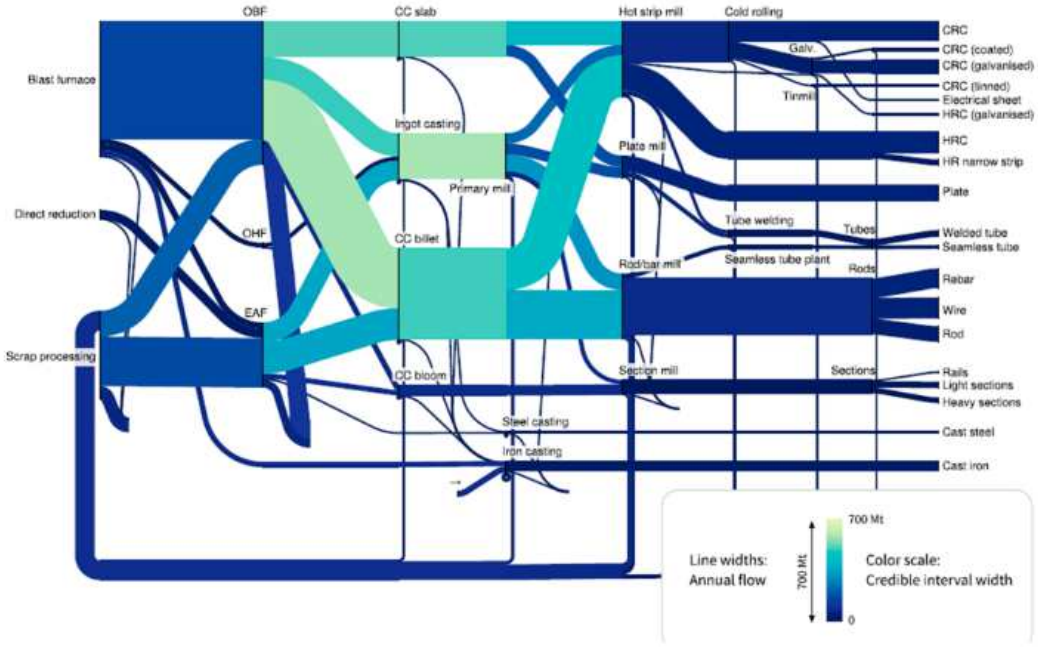

Figure 9 The line width indicates the flow magnitude and the colour the level of uncertainty in the flow (Graedel, 2019).

In the literature, different authors mention the Material Circularity Index (MCI). The MCI is a simplified tool made by Granta design and Ellen McArthur Foundation (EMF, 2015). This tool is a simplified form of MFA that can be applied in practice specifically to evaluate or monitor material circularity. This process is oriented towards the production process and not the design process (Asrani, 2019): it first calculates the linear flow index (LFI) or the virgin feedstock and unrecoverable waste. Figure 10 shows the material flows and the processes needed to recover materials and close loops. The outcome of this calculation rates a material with a number from 0 to 1. The higher the rating, the higher the product's degree of circularity. This tool considers four main product characteristics: the input in the production process (how much material is coming from virgin sources), the utility factor (duration and intensity of usage), the destination after use, and the efficiency.

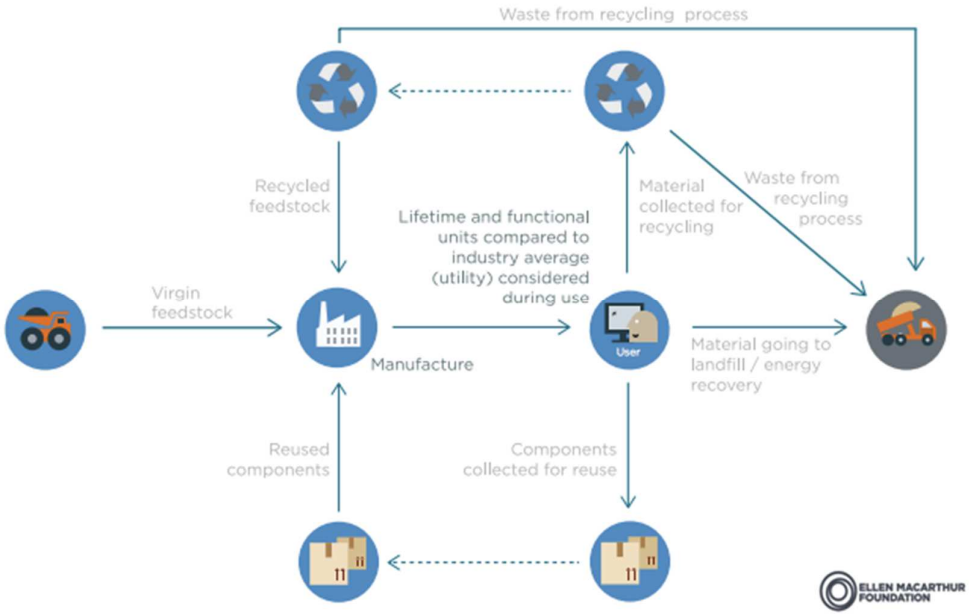

Figure 10 processes and flows (Ellen Mc Arthur Foundation, 2015).

2.2.4.3. Design for X

The literature includes more than 75 'design for X' (DFX), where X is a specific activity (Arnette et al., 2014; Mayyas et al., 2012; Urbinati et al., 2017). Defining each DFX is a complex process, although each can be analysed using the 9R strategies shown in Figure 7, and related within the three main CE principles (closing, slowing, and narrowing resource loops). DFX are activities present in the design phase that ensure one or more of the 9R strategies can be applied to components, parts, and materials during their life cycles. For instance, design for recyclability is related with the R8, as it conceives a component and its parts made with materials that can be processed at the end of life to obtain the same or lower quality in the design process. In this way, design for recyclability enables the R8 strategy, which is classified as a process that enables the closing of material loops. With the help of the relation between the 9Rs and the CE principles, three main DFX can be identified: design for closing the loops, design for slowing the loops, and design for narrowing the loops. This research classifies a set of DFX specified in literature on the built environment industry and exploratory interviews (Table 6) using the 9R model and CE principles defined in Section 2.2.3.

Table 6 Design for X classification (Arnette et al., 2014; Mayyas et al., 2012).

DFX	Variable	Description	9R Strategy
Design for Closing loops	Design for recyclability	Recycling of components, parts, or material	R8
Design for slowing loops	Design for modularity Design for logistics Design for durability Design for disassembly Design for remanufacturing	Design products with modular components Focus of products for efficiency within the supply chain Design products to last longer Disassembly of components, parts and materials Remanufacturing a product to be like new and then reselling the product, often in a different market	R3-R7
Design for Narrowing Loops	Design for customisation Design for minimising material usage Design for energy efficiency	Focus on customers segments through mass-customisation Minimise material used in the supply chain and product Minimise energy usage throw-out life cycle	R0-R2

2.2.4.4. Lifecycle analysis

Lifecycle analysis (LCA) was developed to calculate the environmental impacts related to cradle to grave product or service systems at the micro level. It is an international, standardised procedure, which helps measure the impacts of a project. Using the MFA to identify the material flows is a good starting point for implementing an LCA (Graedel, 2019). This analysis can be carried out according to the following steps:

1) Determine the goal and scope of the analysis
2) Realise a life cycle inventory
3) Make a life cycle assessment
4) Deliver an interpretation of the results

Table 7 LCA purpose and approach (adapted from (Norris, 2001).

Method	LCA
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, form a broad, societal perspective
Activities considered part of the life cycle	All processes casually connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps
Flows considered	Pollutants, resources and inter-process flows of materials and energy
Units for tracking	Mass and energy, occasionally volume and other physical units
Time treatment and scope	The timing of processes and their release or consumption flow is traditionally ignored; impact

	assessment may address a fixed time window impact

The environmental burden of a product can be calculated using this information, and this can form the basis of preventive measures such as choosing better materials, strengthening the MCI degree and DFX targets, and establishing tailored relationships with the customer for the different building layers. Exploratory interviews informed how in some sectors in the building industry, the window of analysis is set considering two lifecycles from production to end-of-life (one from production to end-of-use and a second reuse lifecycle). In the CE, analysing multi-generational uses or multiple LCA for buildings is key, especially for building elements with a long lifespan.

2.2.4.5. Buildings layers

To carry out all methodologies in the adaptive reuse, it is useful to look at the building as a whole that is configured of layers, which are in turn made up of components. This is the 'sheared layer' model (Brand, 1995). In this model, buildings are made of interlinking layers, each with different lifespans. The model defined by Brand is composed of six layers: structure, skin, service, plan, site, and stuff.

This model defines each layer as a conglomeration of components with similar service lives (Disseldorp, 2018). These decompositions of the building suggest that a building is not a whole, but rather a system of interdependent layers. The building's system dynamics are dominated by the "slow" components, and the "fast" ones simply follow along (Brand, 1995). In the building, the site dominates the structure, which dominates the skin, which dominates the services, which dominates the space plan, which dominates the stuff. In the model, the following layers are defined:

Site is the location of the building, the geographical setting within the legally defined lot. Considering its lifespan, "site is eternal" (Brand, 1995 pg.13 pg.13).

Structure is the foundation and the load-bearing elements. These elements are too expensive to be replaced and its structural life is from 30 to 300 years (although only a few buildings are not demolished after 60 years).

Skin is the façade and exterior surfaces. This layer changes every 20 years to keep up with fashion or technology, or for wholesale repair.

Space plan is the interior layout, the solid internal fit-out including walls and floors. Turbulent or dynamic office commercial space can change every three years; particularly quiet residential homes can change every 30 years.

Stuff is the furniture: chairs, desk, phones, pictures, kitchen appliances, lighting, and ICT.

Services as Brand said, are the working guts of a building: communication wiring, plumbing electrical , HVAC and the moving parts like elevators or escalators.

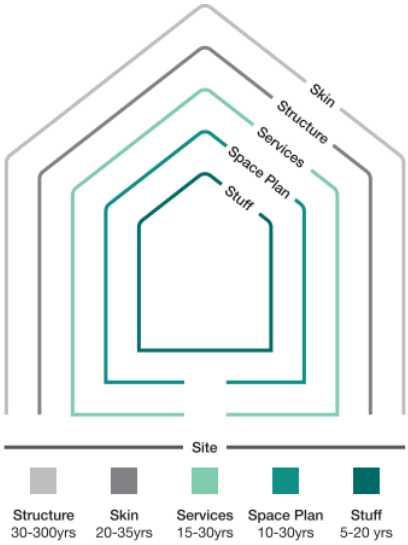

Figure 11 Shared layers (image by Arup &Ellen Mc Arthur foundation, 2020).

CE methodologies and tools can be applied to each of the layers that need to be transformed in an adaptive reuse project. This view is of a building made up of layers that can be separated, both from each other and into components, allowing them to be repaired, reused or replaced, and recycled. The possibility of separating the layers also allows the structural monitoring of the building's lifespan, and the replacement of layers in order to avoid the devaluation of the building as a whole. Thus, the building layer method is important in product analysis to achieve circularity but is also a required parameter for decision making with regards all the business model units in the process.

2.2.4.6. Customisation

Studies of circular renovation in the built environment have reviewed different approaches implemented in circular buildings. One approach is concerned with the way standardised building systems can be customised according to the user (EMF, 2015).

Customisation is a way of slowing, narrowing, and closing the loops. The different approaches to creating this customisable relationship largely focus on product standardisation. The different ways or variables for customisation are related to the DFX methodology, mainly because building component relations with the customer depend on how the component was configured and if customisation was considered in the design process. In other words, designing is a function that allows the building to relate to the customer in different ways during the lifespan: in a responsive way, due to changing demand, or by suggesting new options to the costumer. Modularity and standardisation of layers, components, and parts are important concepts for mass-customisation (A. van Stijn & Gruis, 2019). The literature on BMs in the built environment suggests further descriptions of relations that can be achieved through modularity and standardisation (Table 8).

Table 8. Customer relations

CE Method	Relation with customer	Description	Literature References
Customisation	CE Cooperation	Direct cooperation of customers on CE initiatives	(Urbinati et al., 2017), (Arup & EMF, 2020)
	Adaptable Building Layers	Accommodate more than one use during a building layer lifetime	
	Relocatable Building Layers	Relocation of unutilised or underused assets	
	Flexible Building Layers	Additional renting customers at unutilised or underused spaces (sharing building layers)	

2.2.4.7. CE promotion

Marketing enables communication between different stakeholders. According to the business literature, marketing communication influences customers (Boulding et al., 1994). CE promotion is not a standardised methodology, but rather a way of measuring to what extent the firm promotes CE-based content in its marketing strategy.

A study of BMs and CE carried out by Chiaroni et al. (2016) suggests that the degree of CE at the promotional level can be defined by looking at how CE is promoted in the marketing communication. This includes communities where the customer is involved, or there are systems in place to communicate the CE business vision to them. Research indicates that a CE product can be better positioned using all communication channels to enhance its positive features, create a positive image, and encourage customers to acquire it (Boulding et al., 1994).

2.2.4.8. Life cost cycle (LCC)

The concept of LCC is not new; various lifecycle models have been developed but are not standardised in the industry (Bradley, Jawahir, Badurdeen, & Rouch, 2018). Some of these models do not consider multi-generational uses or multiple lifecycles. Informed CE decisions need to be taken early in the process, so the whole lifecycle of components can be considered. In addition, the LCC model should not be confined to the company, but should also encompass the entire supply chain (Bradley et al., 2018). This has led to an exploration of the integration of the LCA with LCC, and the importance of this in practical decision making.

Table 9 LCC purpose and approach adapted from Norris (2001).

Method	LCC
Purpose	Determine cost-effectiveness of alternative investments and business decisions from the perspective of an economic decision maker
Activities part of the lifecycle	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Monetary units
Time treatment and scope	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted and

	any costs or benefits occurring outside that scope are ignored.

2.2.4.9. Pricing methods

Product service systems (PSS)

Different CE pricing methods can be employed to meet the diversity of demand. Different pricing methods can help close, slow, and narrow material loops and reduce environmental burden. The most cited pricing method is Product Service Systems (PSS). PSS is well known in sustainability circles, and is defined as the tangible products and intangible services designed and combined to jointly fulfil customers' needs (Tukker, 2004). This method is beneficial for CE, but only if the rented or leased product is applied to a 'clean' product (Scheepens et al., 2016b). If the methodologies mentioned previously are applied to the building layers, then PSS helps to achieve a CE. Quantitative methods such as Eco-costs Value Ratio (EVR) are used to assess PSS, and show that when a product saves energy in the use phase but requires high upfront investment, then PSS is usually beneficial (Scheepens et al., 2016b).

Material commodities

The futures contract, which contains detailed information about the recoverable materials (reusable when deconstructed) from the building, would first be placed on the market by the construction client after the building is constructed. The futures contract can then be traded while the building is operational, and the building materials are in use. Buyers are expected to be anyone seeking to manage their position against increasingly volatile material prices such as contractors, suppliers and commodity traders

2.3. Adaptive reuse

The adaptive reuse of office buildings is not a new activity; it has been practiced internationally for many years. Two famous historical examples are the amphitheatre in Lucca from the 2nd century, and the Dutch canal-houses in the 1st century (Remøy, 2010). The new functions incorporated by these two projects have changed over time and these buildings are still being utilised.

When an office building ends up vacant because of changes in market needs, the building, or its location, office owners have four alternatives: consolidate, refurbish, transform, or new build. The most common alternative is to consolidate, this means to wait for better times and try to attract new tenants. This does not usually occur, as the building becomes obsolete: the location or the building no longer fulfil the market needs.

Adaptive reuse is therefore an optimal alternative. However, this option is mostly limited by the different perceptions of the market value of a building. In practice, office owners ask for high prices for their assets, without considering realistic yields. Their yields often do not consider a permanent vacancy of their assets. In addition, there is a fragmented perception in the real estate market sector: office owners or investors are not familiar with the valuation procedures implemented by housing developers. Consequently, the way of thinking and establishing their market value is not congruent to the developer's needs. Nevertheless, there

are cases of successful adaptive reuse that take place when the value perceptions of office owners and developers are aligned.

Adaptive reuse seems like a disruptive, challenging process that presents the developer with a high level of risk and uncertainty. However, this activity can be achieved when the difference in the market value for the new use is higher than the current use value. Adaptive reuse can be done successfully, and the market, building, and location gain as a consequence. For example, 13,000 homes were added to the new stock in the Netherlands through adaptive reuse in 2018 (CBS, 2019a). This was followed by an impact on the maintenance of derelict areas, a preservation potential that required less initial investment than a new redevelopment initiative. Adaptive reuse has the potential to set greater return rates for developers providing social, financial, and environmental benefits.

2.3.1 Spatial planning context in the Netherlands.

Spatial planning is an important aspect of adaptive reuse, as it involves legal situations that can be a key barrier or opportunity for the adaptive reuse of a property. Spatial planning principles are shifting in the Netherlands due to political and socio-economic concerns. Following the financial crisis, the reality of a network society and neoliberal economic dynamics tested the Dutch planning system, which was exposed as inefficient and incompatible with a reality based on connectivity rather than proximity (H. Remøy & Street, 2018). The relationships between national-, regional-, and local-level planning were therefore modified to cut red tape and accelerate development procedures. The New Spatial Act 2008 was part of this free market-oriented sequence of changes that transferred control of spatial development to local governments (H. Remøy & Street, 2018). Spatial planning was further adapted in 2012 to include the Sustainable Urbanisation Procedure, which prioritised developments in the inner city. The Crisis and Recovery Act was also introduced after the crisis, giving municipalities more power in planning decisions, eliminating statutory elements, and reducing the possibilities for people to act against new developments (H. Remøy & Street, 2018). In general, policy in the Netherlands is shifting towards a planning system with fewer regulations, less institutional power, and more opportunities for the free market to steer new urban decisions.

The measures mentioned above had an impact on the building industry, and some were directed specifically towards facilitating adaptive reuse. First, an agreement among central and local governments and market parties to encourage the extraction of vacant office buildings from the market by adaptive reuse took place in 2012 (H. Remøy & Street, 2018). Second, a legal expansion (reform of the Vacancy Act) allowed the temporary adaptive reuse of vacant office space, permitting short-term leasing. Third, the implementation of a vacancy regulation based on the Squatting and Vacancy Act enabled the municipality to receive notification from vacant office owners, give advice, and even oblige the advised party to follow the municipality's recommendations. Fourth, legal obstacles that limited the adaptive reuse of vacant offices were removed.[3]

Political decisions, intended to reduce institutional steps and accelerate economic dynamics and the response to the 2008 crisis, created opportunities for the adaptive reuse of office buildings and opportunities to circular initiatives in the Dutch planning system. For example, the planning system allows municipalities to change land use without imposing as many conditions, and the time to obtain the above-mentioned permit was significantly reduced. Deregulations in the Dutch context have increased possibilities for adaptive reuse.

[3] Adaptive reuse was limited by the quality requirements of the Building Decree, and removing new-build quality requirements from the Dutch Building Decree for the adaptive reuse of vacant office buildings allowed the market to regulate quality.

2.3.2. Housing investor or housing associations

Two of the principal organisations interested in the adaptive reuse of vacant office into housing are housing investors and housing associations. In the Netherlands, these two types of organisations usually expect revenues in the long term. When considering inner-city housing development, they have two alternatives: to redevelop or transform vacant properties.

Free market housing investors have less impact on the real estate market than housing associations. Housing associations own approximately 34% of the housing stock in the Netherlands (Remøy, 2010). In 2018, the Dutch market had 7.7 million dwellings, with 42% being tenant-occupied, of which 70% were owned by housing associations (CBS, 2019b). These organisations are interested in adaptive reuse for two reasons. First, they are interested in developing affordable housing in the inner city, focusing on lower-income users and students. Second, adaptive reuse works as a strategy to gain control of derelict monofunctional areas, usually with vacant offices dating from the 1970s.

Housing associations interested in adaptive reuse are long-term thinking organisations and are interested in inner-city housing developments. In targeting low-income clients, they diverge from the free market tendency to focus on middle- and high-income sectors. Both types of organisation are linked with developers experienced in adaptive reuse into housing.

2.3.3. Architects

Architectural firms can be classified in three ways (Remøy, 2010): strong-idea, strong-service, and strong-delivery firms. Strong-idea firms do not usually negotiate their design outputs with other actors. Strong-service-driven firms are usually open to negotiation and collaboration with developers and other actors during the design process. Finally, the strong-delivery firms usually follow the directions of developers to deliver the project in the most efficient way possible. Developers are aware of this situation and often choose the strong-service and strong-delivery firms for adaptive reuse projects. Strong idea firms are only selected for iconic buildings that have certain symbolic or iconic value within the urban fabric.

2.3.4. Municipalities

Municipalities are interested in the occurrence of adaptive reuse into housing for three reasons. Firstly, to confront urban degradation controlling structural vacancies. Secondly, because the housing market is more stressed in areas where there is more structural vacancy (Remøy, 2010) and municipalities therefore see adaptive reuse as a solution for housing market imperfections. Thirdly, adaptive reuse promotes mixed locations, which improves the liveability and quality of the city. The mechanisms that enable municipalities to facilitate adaptive reuse are maintaining the zoning plan, monitoring structural vacancy, implementing the building decree, and establishing mechanisms for information sharing between developers/investors and public structures.

Today, municipalities are one of the most influential actors in the occurrence of adaptive reuse into housing at the governmental level. As mentioned in Section 2.3.1., the contemporary spatial planning system gives more power and steering capability to local authorities with regards the zoning plan and building decree. Firstly, municipalities can enable the land use change with fewer bureaucratic steps than ever before. Secondly, local governments allow flexible leasing terms of office buildings for temporary adaptive reuse. Current reforms are incentivising adaptive reuse into housing.

Adaptive reuse has been carried out in the built environment for a long time, and there is accumulated knowledge on how to complete these processes. When the market, the building, and the location are suitable in all their aspects, adaptive reuse can deliver high yields. In addition, the assessment of these characteristics will determine the dimension of the investment; if the building is physically suitable and the location appropriate, there is a housing market available and the project can progress.

2.3.5. Adaptive reuse and circularity development

The adaptive reuse of office buildings is one way to impact on the lifecycle of products, components, and materials in the building industry, specifically by slowing the flow of resources by extending their useful life. Therefore, adaptive reuse can to a certain degree be categorised as a circular activity that slows the resource loops refurbishing and remanufacturing the building: usually reusing the 'slow' parts (i.e. structure or the site) and to some degree the 'fast parts' (i.e. skin, service, space plan) of the architectural element (Brand, 1995). Adaptive reuse in the construction industry is therefore a partially circular approach that can create value for organisations and society. The challenge taken on by this research is to investigate how this activity is implemented in an integrated and circular way in practice, through a detailed analysis of the components of the adaptive reuse business logic and delivering a decision support framework for CBM alignment.

2.3.6. Circular adaptive reuse development

Adaptive reuse has increased in practice: 13,000 houses were created due to transformations (CBS, 2019a) in the Netherlands in 2018, representing 14% of the houses added to the stock; 48% of these new homes were built on former vacant offices (CBS, 2019a). The remaining percentage accounts for the adaptive reuse of other buildings such as industrial stores and social amenities. Recent studies have registered the increase in adaptive reuse in the Netherlands over time, highlighting its importance in the built environment (Figure 12).

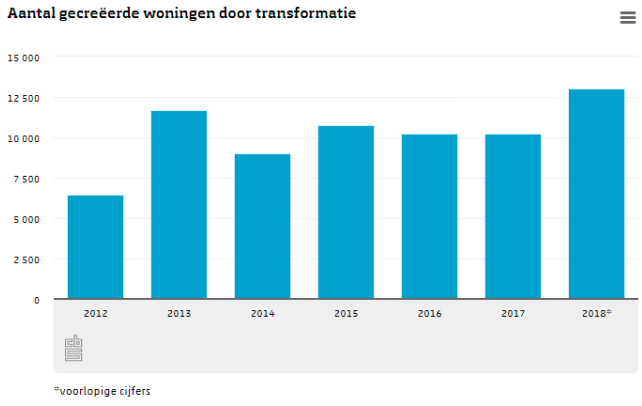

Figure 12. Number of houses created by transformation in The Netherlands (CBS, 2019a).

As the prevalence of adaptive reuse increases, it often still adds significantly to the embodied emissions of the building. There are very few cases of circular adaptive reuse in practice. Secondary databases were consulted to identify organisations at the micro-level in the built environment that are committed or related to CE principles. The 100 members of the Ellen MacArthur Foundation (CIRCL, 2019; EMF, 2017; Urbinati et al., 2017), helped to classify the companies implementing CE principles in the built environment. Google searches for the terms

'circular building transformation' and 'circulair bouw transformatie' in Dutch were used to find more firms related to circular transformation cases, as depicted in Table 10.

Table 10. Organizations in the built environment implementing circularity.

Firm	Sector of activity
Delta Development Group	Built environment / Free market
Building A Research Establishment	Built environment/ Free market
Noble Environmental Technologies	Built environment /Free market
Royal bam Group	Built environment / Free market
TU Delft (MOR)	Education & Research
Eigen Haard	Built environment / Housing corporation
Alliantie	Built environment / Housing corporation
Rochdale	Built environment/ Housing corporation
Stadgenoot	Built environment/ Housing corporation
Woonzorg	Built environment/ Housing corporation

Most of the companies found in the research are Dutch or located in the Netherlands. Companies in the housing corporation sector also show a significant interest in achieving circularity and therefore sustainability in their practice.

2.4. Literature review conclusions

The literature review is divided into three sections: business models, circular economy and adaptive reuse. The first section gives insight into the importance of business processes for the built environment and how to analyse these processes. Then it defines what a BM model is, suggests BM frameworks, and outlines the differences between strategies and BMs. This section also defines how the circular economy BM field is a subset of the sustainability BM field. This section ends with a presentation of the Osterwalder BM canvas as a framework that aligns with the concepts emerging from the built environment, BM and strategy fields. The chapter then includes a definition of each of the nine parts of the canvas and the relations between them (Figure 13).

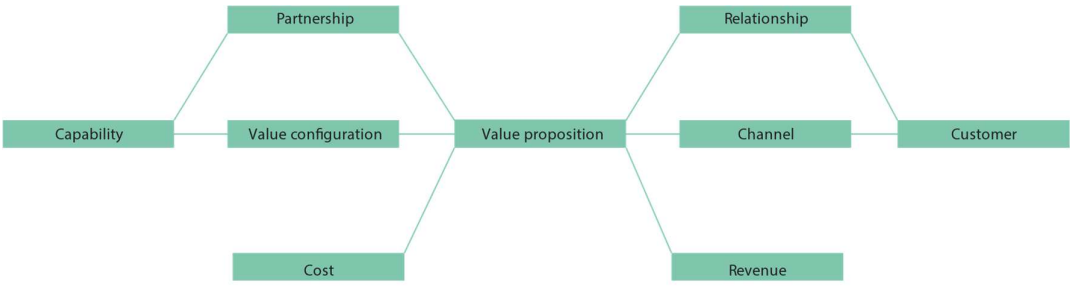

Figure 13. Nine BM blocks (Osterwalder, 2004) (own work).

The second section includes a discussion of the impact of the built environment on finite resources, and the CE as a solution to mitigate resource scarcity or further ecological disasters. Various strategies for implementing material reverse cycles are also presented and defined in the 9R model. These strategies aim to achieve three main CE principles: closing, slowing, and narrowing the material loops in the value chain. CE can be achieved in an adaptive reuse project when the three CE principles are present along the value chain. How can these principles be applied in practice? Standardised and non-standardised methodologies and tools can be used to ensure the execution, quantification, and performance monitoring of a CE system.

The definitions of each CE in the chapter gives an idea of how these elements interact when operating in a value chain. For instance, the Material Circularity Index (MCI) helps quantify and monitor building layers' material circularity in the production process; in the design process, the DFX impacts on the MCI outputs and the way the building layers interact with the user (CE customisation) throughout the lifecycle. Consequently, these outputs have an impact on the way the project is promoted and/or the way revenues can be collected, and expenditures accounted for. However, most of the CE methods in the infrastructure management part of the BM cannot be implemented unless an appropriate project management framework leads to the correct alliances. On the other hand, each CE method only gains meaning if the building layer it pertains to is identified. The selected group of CE methodologies in literature are interrelated throughout the value chain and impact a specific area of the BM (Figure 14).

Comparing Figure 13 and Figure 14, the relations between elements in the BM canvas and the CE methodologies fit. In Figure 14 there is a dashed line that represents the absence of a methodology that fits the customer characteristic BM element. This is because the literature does not include any method or tool to measure or monitor the CE performance of the users. The literature on user characteristics is concerned with the CE pricing methods, which mainly consist of leasing or renting clean products as services. CE pricing methods usually suggest that, for the sake of CE, the user should be a tenant (i.e. lease or rent), which is a rather a limited outlook. Although, in this research, the tenant (rental) characteristic is therefore considered to be aligned with the CE, but further research on this topic is needed to develop a full understanding of the possible CE commercial relationships between the user and the product or service. Evidence and tools to measure CE user characteristics or behaviours as inhabitants of a CE building project are also needed.

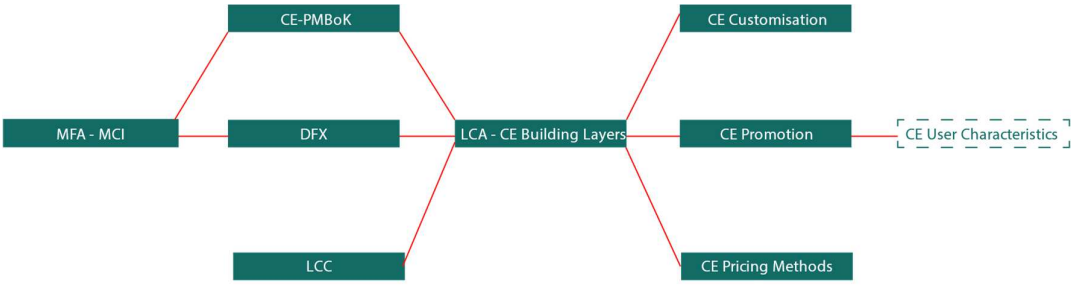

Figure 14. CE methodologies found in literature.

Finally, this chapter introduces the adaptive reuse topic and analyses it in practice in the Netherlands. Analysing different office owner types and their reactions towards vacancies reveals the limitations and drivers of adapting and reusing buildings. Housing corporations and long-term housing investors are revealed to be more likely to be involved in adaptive reuse projects.

The economic and environmental benefits of adaptive reuse are evident in practice, particularly in Dutch cities where commercial real estate vacancies have been drastically reduced by converting them into housing. The shift in urban planning powers from national and regional government to local governments and free market parties has facilitated land use changes and conversions to avoid the devaluation of assets, thus reducing energy emissions and waste.

Even though adaptive reuse is proven to be beneficial, transformation still adds to the embodied emissions of buildings. There are a few organisations in the Netherlands that implement CE principles to adaptive reuse, to create a fully self-sustained renovation process and bring us closer to achieving true circularity. But how can we measure the distance still left to travel before we achieve fully circular adaptive reuse? By using the literature and analysing circular adaptive reuse cases in the Netherlands, this rest of this report defines an answer to this problem.

03

Methodology

3.Methodology

The methods used in the research are described in the following chapter. Participating projects are also mentioned, and the literature framework is explained. At the end, this chapter defines how data from the case studies is gathered.

3.1. Qualitative method

To answer the question of how CE principles can be applied to a BM for adaptive reuse, a qualitative approach is implemented. This research is based on three groups of questions. The first group can be answered through literature and an exploratory interview conducted with a CE expert. This theoretical information from the literature, and supported by practice, is the input to build a draft decision support framework (DSF).

To answer the second group of questions, in-depth interviews are required. The output of these interviews is used to validate the DSF draft and, based on this, identity the practical degree of circularity implemented in the adaptive reuse project case study.

In-depth interviews support the three main themes of this research: BMs, the adaptive reuse of office buildings into housing, and CE principles. The last question depicted in Figure 15 gathers all the data to provide recommendations and a final framework that can be used as a tool for assessing or prescribing BMs for adaptive reuse. The previously described methodology is depicted in Figure 15.

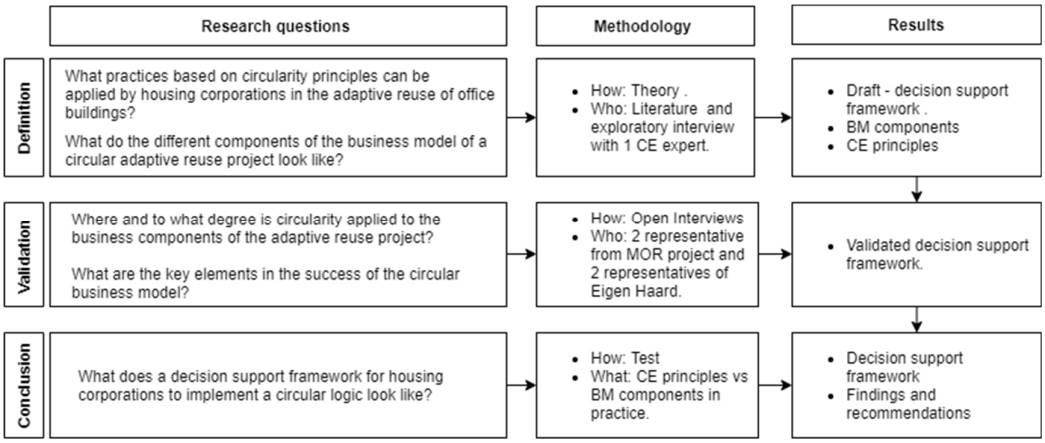

Figure 15. Methodology (Own work).

3.2. Participating firms and projects

The projects considered in this research are Noorderliefde by Eigen Haard and the MOR project by TU Delft. These two projects are considered circular projects, meaning that they implemented the key CE principles defined in this research in their BM: slowing, narrowing, and closing the resource loops.

3.2.1 Case study A

The first project is in northern Amsterdam, at Strekkerweg 75. The building was developed by the Eigen Haard housing corporation. It was originally constructed as an office building in 1993, and was adapted into housing by Eigen Haard in 2018. It was opened to the public in June that year, and directed to vulnerable status people, formerly homeless people, and students. This transformation involved the provision of 33 small dwellings.

3.2.2. Case study B

Modular Office Renovation (MOR) is a project that represented TU Delft in the Solar Decathlon competition in Hungary in 2019. The competition focused on design and aimed to deliver the most sustainable home possible for the future. The challenge consisted of being positive in five elements: air, water, energy, biomass, and material. The MOR team decided to tackle the housing shortage and environmental problems while simultaneously addressing office vacancies. To do this, the MOR team suggested a mixed-use vacant office transformation into affordable housing project. The transformation was done in the iconic Marconi towers in Rotterdam.

3.3. Literature framework

The main framework used in this research is based on the Osterwalder BM canvas and its business elements and sub-elements, as presented in Section 2.1.3. This framework is adapted to explore how CE principles are considered in the BM for an adaptive reuse project. The canvas is based on the concepts of the balanced scorecard developed by Kaplan (2005 #170). In the built environment field, Spencer and Winch developed a balanced scorecard for evaluating the performance of constructed assets (2009 #190) to improve a client's business processes: information flow, resource flow, material flow, and people flow within the asset's[4] spatial syntaxis. With this, Winch suggests a close relationship between business processes and an asset's spatial qualities. A relationship where people and material flows are spatial as they demand space, and information and financial resource flows are non-spatial. Winch's business topics in the built environment align with Osterwalder's BM canvas business topics in the business field: information management, customer interface, and financial aspects related to the product, as shown in Figure 16. Literature framework adapted from Osterwalder (2004) (own work).Figure 16.

Considering these two approaches, the DSF makes the distinction between information flows and material flows suggested by Winch (spatial and non-spatial processes). In Osterwalder, these two aspects are both part of the field of infrastructure management and the customer interface. The DSF is organised in four main CE modules: Infrastructure, user, and financial. All modules are related with the building layers concept as explained further in this chapter (Section.3.7).

The four topics (dotted line areas), nine elements (in light green), and sub-elements (in dark green) suggested by the Osterwalder canvas are shown in Figure 16.

[4] Winch (2009) considers buildings as assets rather than artefacts. The latter are considered things that cannot create value for owners and users, while the former can create value because of its design, in this case because of including CE principles along the value chain.

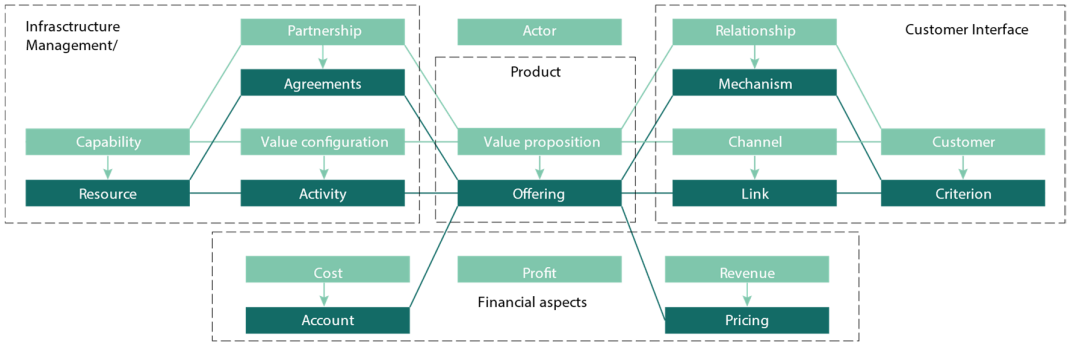

Figure 16. Literature framework adapted from Osterwalder (2004) (own work).

3.4. Adding the Circular Economy to the Business Model

The BM topics and elements depicted in Table 11 are gathered from literature and explained in detail in Section 2.1.3. The BM canvas is used as the basis for identifying CE elements in the adaptive reuse value chain. The nine blocks shown in Figure 17 and described in Table 11 depict the structure for the analysis. The elements and sub-elements defined by Osterwalder are developed in the table, and an additional column for CE sub-elements is included on the right. These CE sub-elements are the vehicle to exploring the degree of circularity in the value chain.

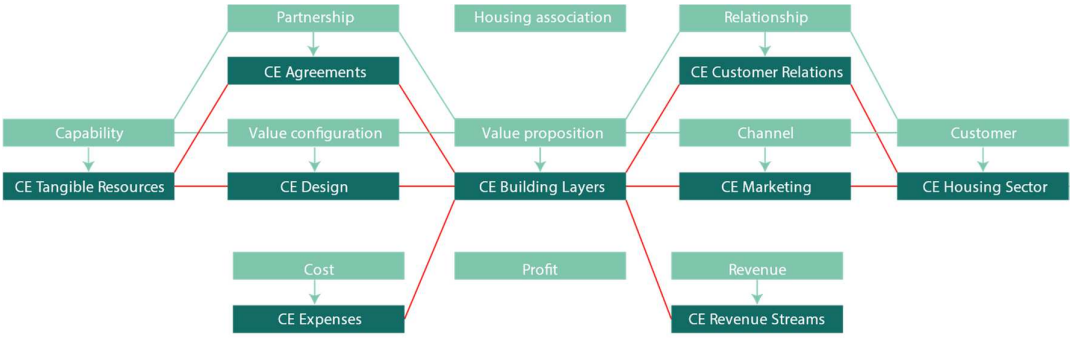

Figure 17. Overview of CE sub-elements in the BM canvas (Own work).

Table 11.Detailed overview of Osterwalder BM elements (Osterwalder et al., 2005) and CE sub-elements suggested in this research.

Topic	Element	Sub-element	CE Sub-Elements
Infrastructure Management Describes the value network that generates economic value	**Partnerships** A voluntary cooperative agreement between 2 or more companies to create value for customers. Partnerships are a set of **agreements**.	**Agreements** are the terms and conditions of a partnership with an actor.	**CE Agreements** The CE terms and CE conditions of a partnership with an actor.
	Capabilities A voluntary cooperative agreement between 2 or more companies to create value for customers. Partnerships are a set of **agreements**.	**Resources** can be tangible, intangible and human.	**CE Tangible Resources** Input materials and energy emissions in the project involved in reverse cycles.
	Value configuration Describes the arrangement of activities and resources that are necessary to create a value proposition. It is mainly a set of **activities**.	**Activities** are the heart of value creation. They are actions companies perform to do business and achieve goals.	**CE Design** the design required to accomplish CE Building layers.
Product Covers all aspects of what a firm offers its customers	**Value proposition** Represents value for target customers and is based on capabilities. The value proposition is a set of **offerings.**	**Offerings** can have a description, a reasoning (i.e. effort reduction), a value level (i.e. utility), a price level (i.e. high end) and a life cycle (i.e. renewal).	**CE Building Layers** CE interrelated layers that configure the adaptive re use project, the asset.
Customer interface Describes how a company reaches its customers	**Distribution channel** How a company delivers a value proposition to a target customer segment. How a company gets in touch with customers. Channels create **links** between the company and the customer.	**Links** describe a specific channel role. As offerings, they can reduce risk, effort or have a use. To reveal the role of the links a customer life cycle analysis needs to be carried out.	**CE Marketing Communication** Describes the communication channels used to promote CE information.
	Relationship management The relationship a company establishes with a target customer segment. It is based on customer equity and is a set of relationship **mechanisms.**	**Mechanisms** describe the function the relationship accomplishes between the company and its customers (i.e. customisation or trust).	**CE Customer Relations** Describe the function a CE relationship accomplishes between the building layers and the user.
	Target customer The type of customer the company wants to address. It is a set of **criterions**	**Criterions** define characteristics of target customers.	**CE Housing Sector** Are the CE user characteristics (i.e. social tenant).
Financial aspects Influenced by the other logic components. Describes how the company makes profit.	**Cost structure** Measures all monetary costs incurred by the company. It is an **account**.	An **account** is a registry of transactions (expenses) of a certain category.	**CE Expenditure** Registry of transactions (expenses) related to the CE.
	Revenue framework The way companies make profit. It can be composed of one or several **revenue streams and pricing elements.**	**Revenue streams and pricing methods** describe the incoming money for the value offered by the company, and what mechanism is used to determine the price of the value offered. A stream type is an economic activity (i.e. lending, selling, advertising). A pricing method can be fixed (i.e. pay per use), differential (i.e. based on customer) or market oriented.	**CE Revenue streams** Describe the incoming money for the value offered by the company, and what mechanism related to the CE are used to determine the price of the value offered. A CE stream type is an economic activity compatible with the CE principles (leasing, product service systems).

In this research, CE is considered a possible supplementary feature to the traditional way of seeing business suggested by Osterwalder (2004). As this research aims to reveal the degree of circularity in each part of the value chain, attention is paid to the inclusion of CE principles in the elements and sub-elements of the BM canvas. The method of this research assumes that the

main BM element in the canvas can be linear (with no CE principles) and explores whether a CE sub-element can be found when the main element is separated out into sub-elements. Avoiding a binary notion where only a complete CE or no CE is possible, this research does not try to establish or evaluate if a main BM element is completely circular or not. For example, it does not evaluate if the BM partnership element is completely circular, but rather whether there is one or more CE agreement comprising the partnership element. In this way, the degree of circularity is explored in the sub-elements layer that configure the BM element in the Osterwalder model.

3.5. CE Methodologies and the business processes.

Due to the complexity of evaluating and monitoring CE in practice, standardised and non-standardised methodologies designed from different disciplines within the CE field and directed to different business processes are selected for this task. The CE method attributes determine if a sub-element is to a certain degree circular. A CE sub-element in the value chain "is cause of" the CE method or tool implementation.

The CE methodology is understood as a fundamental activity aiming to achieve a degree of circularity within BM elements for adaptive reuse. CE methods are discussed in greater detail in Section 2.2.4 (with reference to (Arnette et al., 2014; Arup & EMF, 2020; Graedel, 2019; Mayyas et al., 2012; Mentink, 2014; Scheepens et al., 2016a; Schraven, Bukvić, Di Maio, Hertogh, & Recycling, 2019; Tukker, 2004; Urbinati et al., 2017; A. van Stijn & Gruis, 2019; Versteeg Conlledo, 2019). They are a mix of standardised and non-standardised procedures that can be simplified by tools and variables for their implementation in practice. CE experts suggest that these methods are not often implemented in practice due to their complexity, and other ad hoc tools are therefore used (Stijn, 2020). These methods and tools are useful for evaluating, enabling, or monitoring the performance of reversing material cycles in the different parts of the adaptive reuse value chain. Each CE method acts as an attribute of the BM sub-elements as shown Figure 18. CE methods are practices that add a degree of CE when implemented to a specific area of the value chain.

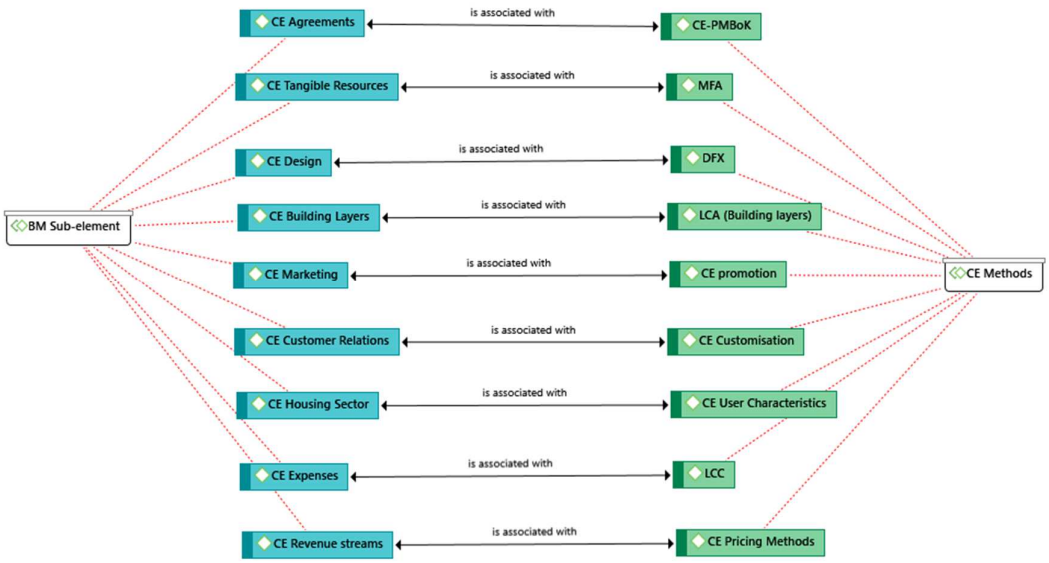

Figure 18. Business Model sub-elements and CE methods relation (own work).

Full implementation of the CE methodologies is highly complex, so CE implementation in practice needs to be analysed using variables. A CE expert and an in-depth review of the literature helped select a set of variables or tools used to implement the CE method in practice. Thus, CE methodologies can be broken down into a set of CE variables that can be found in study cases (Figure 19).

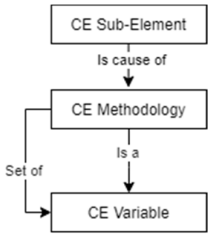

Figure 19. Relation between CE methodologies and CE variables (own work).

Table 12 below shows the variables found in the literature in relation to each CE methodology. Variables are supported by more than one author in literature or the CE expert interview (all the authors are listed in the literature review). Detailed description and references of each variable and the impact of the variables on a project are set out in the literature review in Chapter 2.2.4.

Table 12. CE methodologies and variables mentioned in literature and CE expert interviews, and used in the DSF draft.

CE methodology	CE assessment variables	References
Project management body of knowledge (PMBoK)	Project scope management	(Versteeg Conlledo, 2019) (van den Berg, 2019)
	Project cost management	
	Project procurement management	
	Project integration management	
	Project financial management	
	Project human resource	
Material flow analysis (MFA)	Material circularity index	(Saidani et al., 2017) (Rijkswaterstaat, 2015)
	MFA	
Design for X	Design for closing loops	(Mayyas et al., 2012) (Arnette et al., 2014; Bocken et al., 2016; EMF, 2017)
	Design for slowing loops	
	Design for narrowing loops	
Life cycle analysis (LCA)	Consecutive LCA	(Graedel, 2019; Scheepens et al., 2016a)
	Building layers	
CE Promotion	CE social media	(Boulding et al., 1994; Urbinati et al., 2017)
	All channels	
	CE website media	
	CE In store communication	
CE Customisation	CE cooperation	(Arup & EMF, 2020; Tukker, 2004)
	Adaptable building layers	
	Relocatable building layers	
	Flexible spaces	
User characteristics	User as customer	(Scheepens et al., 2016a; Tukker, 2004)
Lifecycle cost (LCC)	LCC-LCA integration	(Norris, 2001; Rijkswaterstaat, 2015)
Pricing methods	Product service system	(Scheepens et al., 2016a; Tukker, 2004)

3.6. CE building layers

The building layers model (Brand, 1995) is used in the DSF to explore the effect that the building layer configuration has on the asset's degree of CE. It is "cause of" all other CE business elements in the infrastructure, asset, customer, and financial modules. Consequently, the CE methods associated with the CE elements are all also related to the building layers (Figure 20).

All aspects and elements in the DSF are analysed through Brand's (1995) sheared layers model. In this model, the building is understood as a set of interdependent layers with different lifespans. Each layer has a different lifespan and can be understood separately from the others during its lifecycle. Each layer is involved in different stages of the design, production, and operation processes. The sheared layer model allows the DSF to analyse the evidence of CE principles in each of the building layers separately, and from different perspectives of the BM narrative. The image below shows an overview of the relations between the proposed CE methods, CE business elements and the CE building layers.

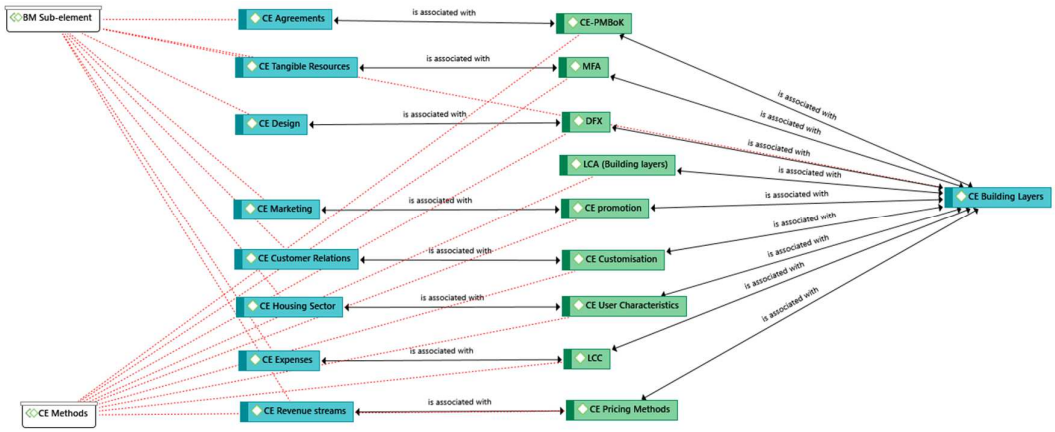

Figure 20. CE building layers element are the cause of the other CE elements. Consequently, all CE methods are also associated with it.

3.7. The CE measurement tool

The degree of CE explores to what extent the main CE principles found in literature are pursued by the company in the adaptive reuse project, or how far they are from achieving a fully circular project. The concepts used to measure circularity are depicted in Table 13. The three main CE principles of slowing, narrowing , and closing the loops are mentioned by different researchers (Bocken et al., 2016; EMF, 2017; Lüdeke-Freund et al., 2019; Mayyas et al., 2012; Potting et al., 2017; Urbinati et al., 2017; A. van Stijn & Gruis, 2019). These three CE principles are related to the 9R CE activities defined by Potting et al. (2017). They can be used to determine whether the three main CE principles are present within the building layers from different perspectives of the value chain. In the DSF, the execution of the CE principles within the BM determines the degree of circularity in it: achieving only closing the loops indicates a low degree of circularity, closing and slowing the loops indicates a medium degree of circularity, and when all three principles are fulfilled there is a high degree of circularity (Figure 21).

Table 13. Main CE principles and CE evaluative methods found in literature adapted from Potting et al. (2016).

Main CE Principles	CE Activities	Description
Narrowing Loops	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product

	R1 Rethink	Make product use more intensive
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources
Slowing Loops	R3 Reuse & Distribution	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair & Maintenance	Repair or maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose & Cascading	Use discarded product or its parts in a new product with a different function
Closing Loops	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of materials with energy recovery

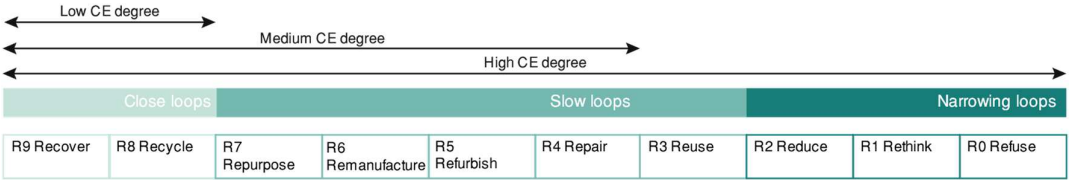

Figure 21. CE degree measurement based on the 9R model and CE principles (own work).

The measurement tool described in Figure 21 is used at two moments when employing the DSF. First, the CE degree measurement tool defines if the CE variables applied to the building layers are closing, slowing, or narrowing the loops. For instance, when applying a Material Circularity Index or a modular façade design, the CE degree measurement tool defines if these activities are closing, slowing, or narrowing the resource loops.

Second, the CE degree measurement tool is used to add the different CE principles found in the first moment (which was applied to each building layer from the different perspectives along the value chain) to calculate a total CE score for each module. These results would be the total CE degree outputs of each CE building layer in the DSF's four modules.

3.8. DSF overview

Figure 22 shows an overall view of the DSF. The four main CE processes or modules (in yellow) contain nine CE business elements (in blue) that must be present to a certain degree to consider a CE value chain for adaptive reuse. These CE business elements are made possible in practice through the application of CE practices or methods. The image shows each of the methods (in green) related to each element in the value chain. All of the CE methods are applied to the building layers element. They can be applied in the adaptive reuse project by using different standardised and non-standardised activities expressed as the variables in Table 12. The variables found in literature are validated by in-depth interviews in two case studies. Further, the CE measurement tool is used to assess the degree of CE for each variable impacting on the adaptive reuse project individually. Lastly, the CE measurement tool is used again to calculate the total CE degree of the whole business process or module.

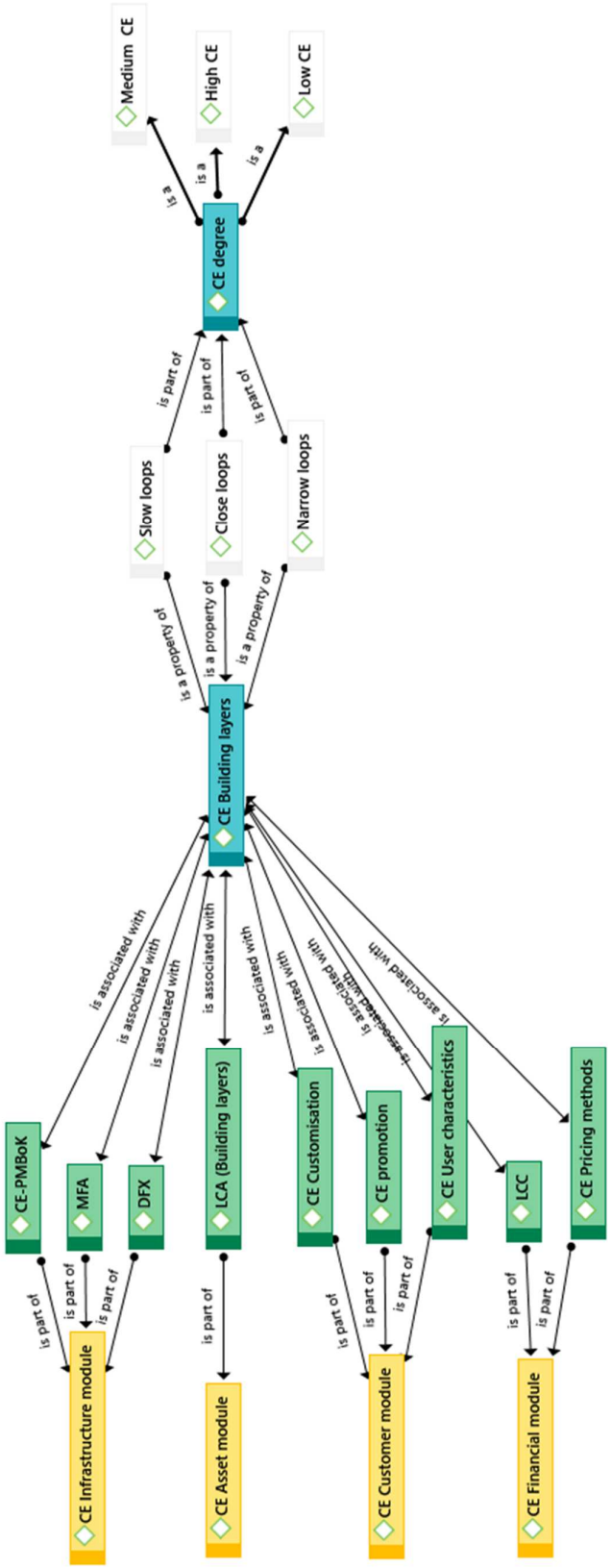

Figure 22. Overview of the Decision Support Model concepts (own work).

3.9. Data collection

Interviews are used to construct, validate, and operationalise the DSF. The questions considered each of the nine elements in Osterwalder's BM canvas. All the interviews were recorded, transcribed, analysed, and used to build and validate the DSF. The interviewees are listed in Table 14. The channel used to approach the interview is also recorded in the table below, as the coronavirus pandemic limited the possibility of in-person contact.

Table 14. Interviewees

Interviewees	Institution	Role	Channel
CE expert (1)	TU Delft	CE Renovation Expert	Video conference
Organisation Representative (2)	Eigen Haard	Noorderliefde Project Leader	Video Conference & E-mail
Organisation Representative (3)	Eigen Haard	Noorderliefde Project Manager	E-mail
Organisation Representative (4)	TU Delft- MOR	MOR Faculty Advisor	Video Conference
Organisation Representative (5)	TU Delft - MOR	MOR Feasibility Committee	Video Conference

3.9.1. Semi-structured Interviews

The semi-structured interviews combine a predefined structure of questions with the open questions of a non-structured interview. The main aim of these interviews was to gather systematic information about specific topics (Wilson, 2013). To do this, the interviews followed an interview protocol and explored specific topics and subtopics from the BM canvas in a flexible and non-structured way, allowing new topics to emerge. This type of interview has the advantage of being able to reveal unknown issues related to predefined topics. However, it also has the disadvantage of the "interviewer effect," where the background, age, gender, and other demographics influence how much information people are willing to provide (Wilson, 2001. pg. 26).

3.9.2. Interview protocol

The semi-structured interview follows an interview protocol (NCPI, 2003) driven by the literature framework. This interview protocol is divided into three main sections: Introduction, Interview Background, and CE Business Model. In the first, the topic of the interview and why the interviewee was invited to participate in the research were explained. The second section was divided into the eight themes listed below. The third part explored the interviewee's background and expertise.

1) Partnerships/ CE Agreements
2) Capabilities/ CE Tangible Resources
3) Value Configuration / CE Design
4) Value Proposition/ CE Building Layers.
5) Distribution Channel / CE Marketing Communication
6) Target Customer / CE Housing Sector
7) Relation Management/ CE Customisable
8) Cost Structures/ CE Expenditures
9) Revenues / CE Pricing Methods

Each theme was directed towards one specific topic of the literature framework and CE involved in these processes. At the end, there was also time for further comments, conclusions, and recommendations for further sources of information.

Each interview was recorded and transcribed with the permission of the interviewees. The interview protocol can be found in the appendix. The full names of the interviewees are kept anonymous.

3.9.3. Triangulation

Data triangulation is important for interview validation and avoiding chance (Versteeg Conlledo, 2019). Triangulation in this research is done with interviews with two representatives of two different projects, and one CE expert. One of the cases has been used as a case study in previous research (Asrani, 2019). Thus, this research looks at where more than one source of information converge on one same set of facts or findings, for the purpose of triangulation (Yazan, 2015). Interviews have strengths and weaknesses. On the one hand, they are directed by the interviewer to the topic where they require further knowledge. On the other hand, there is a risk of response bias and reflectivity (Versteeg Conlledo, 2019). The first is a bias caused by a biased question, and the latter by the interviewee recounting what they think the interviewer wants to hear.

When two or more interviewees converged on one topic, a cluster was created. This cluster was later used to validate the framework developed as part of this research, according to the literature and CE expert advice.

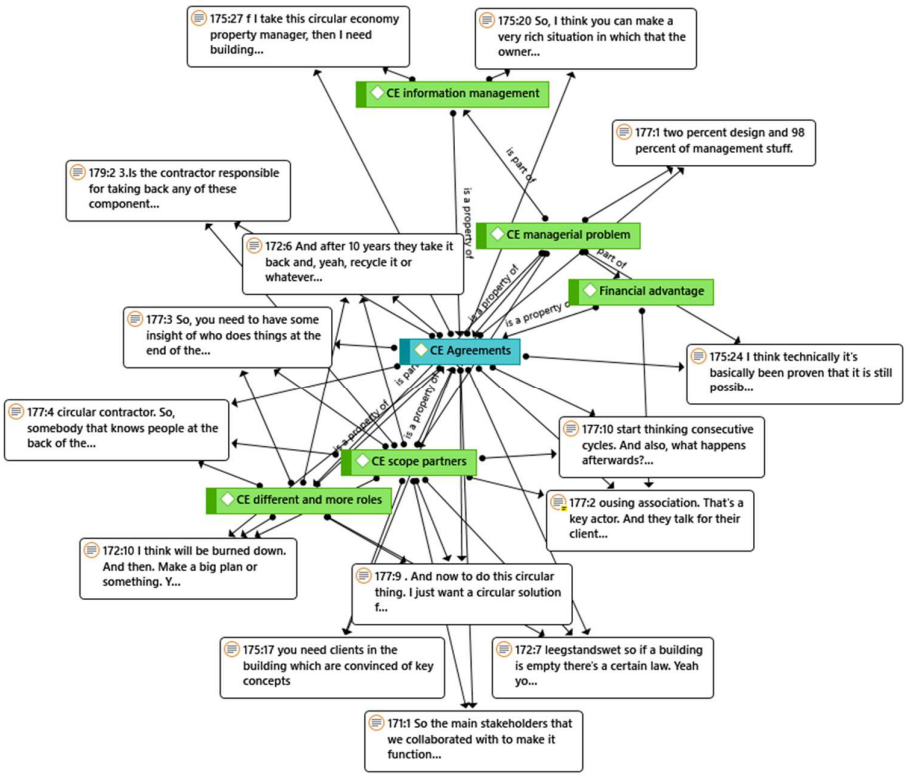

Figure 23. relation between business CE sub-element CE agreements with interview quotations using Atlas TI software. In blue the interview topic and in green five clusters found (own work).

Clusters help validate and define the CE methodologies and tools discussed in literature and with a CE expert (Figure 24).

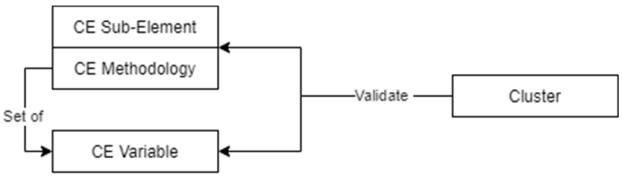

Figure 24. Relation between interview clusters and the BM element

04

Case Studies

4.Case studies

Two projects and one CE expert were chosen to gather information and triangulate data. The two projects were selected for the CE principles they included. The fact that they are adaptive reuse projects, the possible access to information, geographical location, and suggestions by Master's thesis mentors were also taken into account. The information published below comes from online information and that offered by the representatives of each case study.

4.1. Case study A

Case study A is a project developed by Eigen Haard a housing corporation in the Netherlands, in northern Amsterdam, Strekkerweg 75. The building was built in 1993 and was left vacant for five years in 2013. During this period of vacancy, the building was used partially by start-ups. Afterwards, Eigen Haard decided to carry out an adaptation to create 33 apartments for mixed user targets: vulnerable social segments, students, and starters in a very short time and saving resources using CE principles. The adaptive reuse started in January 8 2018 and was delivered in May 30 2080.

Thanks to a reform in the Vacancy Act that stimulated transformations allowing the temporary adaptive reuse of vacant office space, permitting land use changes and short-term leasing (H. Remøy & Street, 2018). The Noorderliefde project could therefore be realised as a temporary project lasting 10 years. In addition, the fact that this adaptive reuse project was carried out under the Vacancy Act meant that Eigen Haard could get in touch directly with vulnerable social segments independently, without using WoninNet: a centralised social housing system. This allowed Eigen Haard to reach out to homeless customers who are not registered at any address and therefore do not appear on any waiting lists in the WoninNet system.

Figure 25. Noorderliefde building by Eigen Haard. Left: own image, right: Etro.nl.

Users are involved in the management of the building, from renting communal areas and deciding on mural paintings and the name of the project formerly called Starters Up! (Figure 25). Noorderliefde is a project recognised in the media as a social experiment that mixes different social segments. In a less well-known way, this project is announced as a CE project over different channels (online webpages, social media, and third-party journalism). It is recognised as a CE project because CE principles were directly and indirectly implemented by third parties like service providers and contractors. In the early stages, the four main actors were all involved in the CE, that is the main contractor in charge of the transformation, the government that allowed the use change, the housing association, and the kitchen and stuff layer provider.

> "The contractor drew up a budget that was also a technical description. The installers sat at the table from the first preparations. This is a completely different way of working than we normally use. Then we make specifications or technical design together with the architect.

Now for the 'architectural work' I engaged an engineering office. A 'lean' process. Rarely seen such a rapid renovation from start to finish. Circularity was the starting point, which means that we have tried to reuse as much material of reasonable quality as possible." Said Eigen Haard's Noorderliefde project manager (translated from Dutch).

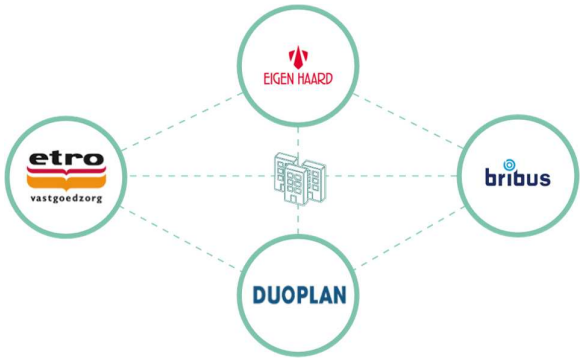

Figure 26. Actors participating in Noorderliefde involved in the CE (own work).

Etro is a construction company located in the Netherlands. Their online public communication documents show that they are involved in the project due to their CE vision and philosophy (Etro). Their communication strategies mention how their circularity ambitions were implemented in the Noorderliefde project by reusing components and using non-environmentally harmful materials.

Figure 27. Collaboration companies for the circular kitchen (Bribus.nl).

Bribus has implemented circular kitchens specially for the housing association sector, as changes in kitchens are constantly required in this sector. Bribus, with the help of specialists in different fields, including TU Delft, explored CE methodologies that helped include CE principles in the Noorderliefde project's kitchen.

Duoplan, is a Dutch architecture design firm whose public communications also mention their philosophy and vision of working towards the CE (Duoplan). Douplan and Eigen Haard worked closely together from the beginning to develop the technical design and specifications followed by the main contractor.

Eigen Haard is the long-term investor that facilitated the building of a network of actors committed to the CE, and that worked with them throughout the process to reduce costs by reusing materials and reducing the investment, thus allowing a low rent for the vulnerable social sector.

Figure 28. Based on video documentation a typical plan. On the left is the reused façade and structure, on the right is the Noorderliefde space plan: three types of dwellings (own work).

The renovation took place reusing a concrete column and beam structure. In this structure a central core connects the building vertically and the column and beam structure allows for an open space around it. Figure 28 shows how the former office space could be transformed into a residential building with three type of apartments. The smaller, Type A apartments are 18m^2 and the Type B and C ones are approximately 28 and 38 m^2 respectively.

Due to the reuse of material and early participation of service providers, this project could be completed in a few months, using the least amount of resources possible by reusing material building components.

4.2. Case study B

As mentioned in Section 3.5.2 Modular Office Renovation (MOR) is a project that represented TU Delft in the Solar Decathlon competition in Hungary in 2019 (Figure 29).

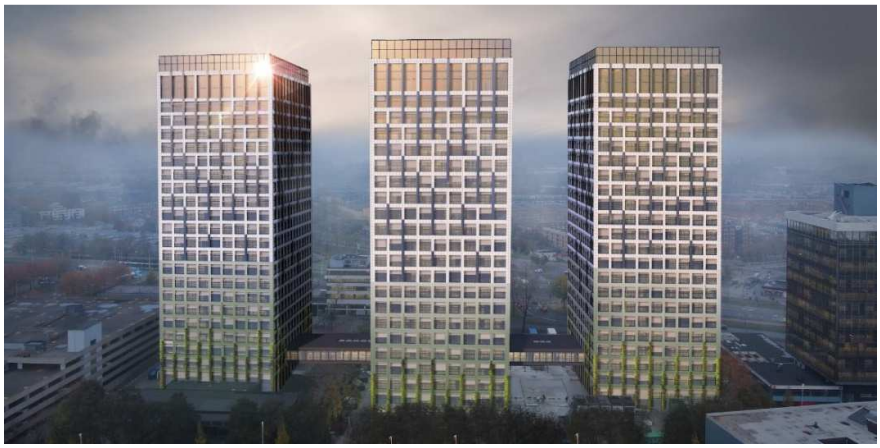

Figure 29. Marconi towers (image by TU Delft).

It is a conceptual project directed towards the Marconi towers in Rotterdam. These towers were built in the mid-1970s. They consist of a floor plan with a central core with an open floor around. This design is a global typology of offices and is used as a representative example of an unoccupied office building. Thus, the modular approach and the circular strategies applied could be implemented in other buildings with the same typology.

The MOR team approach was based on circular transformation, including CE principles in its implementation. Thus, they addressed the transformation of the vacant office building to provide affordable housing for vulnerable target sectors. To do this, the model also suggested a lease-based housing relationship in the business model, in a conceptual- and academic-oriented way.

MOR is an academic project made by the joint effort of students, professors, and market experts. Being an academic and practical project, it is important to this research because it provides insight into how theoretical knowledge can be implemented in practice. This project tries to include academic research in its actions, and applies them to the practical world. On the other hand, the MOR project allows for a specific focus on how the technical and managerial part of the business model can be coupled without any policy intervention. Finally, the academic dimension of this project makes it accessible for gathering information through in-depth and transparent interviews.

The concept of the project was to create flexible modular units and components in order to respond to the changing multi-use demand.

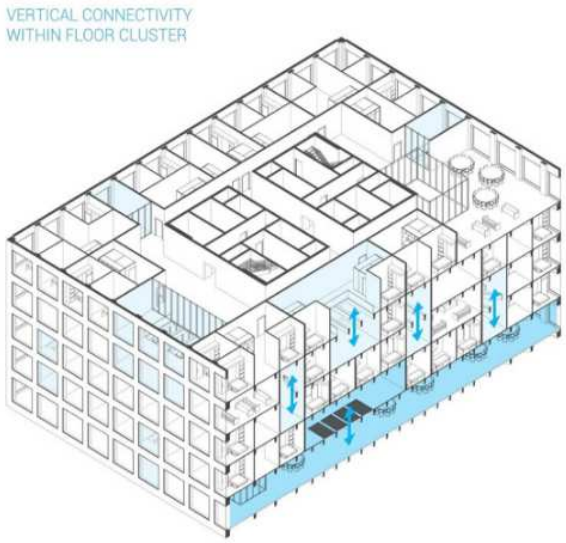

Figure 30. MOR project typical central core structure and open floor plan (MOR).

In this project, around 82 partners were involved in achieving circular and module components. Achieving each building layer involved diverse partnerships. As this was a conceptual project, the technical and management processes aim to achieve a high degree of circularity, making this case study a good comparison that sets a high degree of CE achieved by the industry.

05

Case studies results

5. Case studies results

This research explores the CE in the adaptive reuse of office buildings by housing corporations. It considers the BM an essential unit to visualise and study the rationale behind how a firm creates value. To do this, the business elements suggested by Osterwalder are analysed and the three CE principles are used to explore how a high, low, and medium degree of circularity can be achieved. CE methodologies and tools found in literature are identified within the value chain to ensure the CE principles can be realised. Exploratory interviews with CE experts and the literature signal the importance of methodologies and tools in achieving a CE. These concepts led to a draft framework to assess the level of circularity accomplished in a project, thus helping the investors to make decisions about their assets.

The framework draft is validated further using in-depth interviews within the MOR and Noorderliefde project case studies. The interviews were mainly divided into four areas in the value chain: infrastructure management, product/building layers, customer interface, and financial aspects. As mentioned in Section 3.3, these four main topics are divided into nine business elements, where CE sub-elements in the adaptive reuse of offices by housing associations can be found.

5.1. Outcome of in-depth Interviews

In-depth interviews with project representatives helped validate the BM elements, CE sub-elements, CE methodologies, and their variables. Interviews were fully recorded and transcribed. They explored the implementation of a CE variable or method that validates the existence of CE principles within the nine BM elements. When two or more interviewees converged on an aspect related to one of the CE sub-elements, a code was created. Table 15 shows the clusters that were defined during this process.

Table 15. Clusters for the nine business CE sub-elements.

CE sub-element	Cluster	Mentioned by:
CE Agreements	CE as mainly a managerial problem**	1
	CE scope partners	1,5,4,2
	Information management	1,4
	CE different and more roles	1,2,4
	Financial advantage	1,4
	Early procurement	1,3
CE Tangible Resources	Material circularity	1,5,2,4,3
	Material reuse+ analysis*	1,2,3,5
CE Design	Closing loops	1,5,4
	Slowing loops	1,5
	Narrowing loops	1,5,4
CE Building Layers	Consecutive LCA	1,2,3,4,5
	Building layers & components	1,2,3,4,5
	End-of-life service providers*	1,2
CE Marketing	Information sharing & transparency	1,4,2,5
CE Customer Relations	User participation	4,2,5
	Adaptable	1,4
	Flexible	4,2
	Relocation	4,3,2
CE Social Housing Sector	User as tenant	1,2,5
	Circular stakeholder as owner	1,2,3

	Ownership as long term investment	1,2
CE Expenditure	LCC and LCA integration	1,4
CE Revenue Streams	Product service systems	1,2,3,4,5
	Sell and take back **	1
	Material commodities**	1
	Diverse pricing methods	1,4

*Topics found in case studies interviews but not mentioned in the literature.

**Topics mentioned by CE expert but not found in the case study in-depth interviews.

5.1.1. CE agreements

This business CE sub-element involves the terms and conditions of partnerships between actors in the value chain. During interviews with representatives of MOR project and Noorderliefde, four different topics were identified.

Cluster – CE as a managerial problem

Firstly, the CE is seen as a managerial problem more than a technical one. As the expert in CE renovations, said, *"[it's] 2% design and 98% management."*

A MOR representative also argued, "*I think technically it's basically been proven that CE is still possible to handle. Technically it is possible. But still the financial system is very focused on a growth which is not viable in itself*."

In the building industry, there are existing technical CE methods and tools that are already proven to work. The knowledge on how to use them is reported in scientific reports and case studies. This gives a high priority to the management part of a project in achieving a CE and highlights the importance of creating management tools for this purpose.

Cluster – CE long-term scope partners

The CE partners' long-term thinking in the project was mentioned as an important condition in a circular project. As the CE expert explained, at the beginning of the process *"you need to have some insight into who does things at the end of the process, but also maybe partners that can supply second-hand material […] you will need a circular contractor. So, somebody that knows people at the back of the supply chain."*

In both the Noorderliefde and the MOR projects, this aspect was also important regarding the stuff building layer. As the project leader of Noorderliefde revealed*, "after 10 years' service, suppliers take it back and recycle it."*

In the MOR project, the shared scope between the partners at the beginning of the process was important. As a representative from the MOR team, pointed out*, "We [the MOR team] conjecture on a lot of rules and conjecture at how the business model would function… and the service providers told us about the [CE] specifications."*

In adaptive reuse, a long-term vision needs to be established by all the actors involved in the projects from the start. Service suppliers, governments, and investors need to align their scope to achieve circular adaptive reuse. As the MOR representative stated, "*normal short vision investors are not capable of looking beyond the short-term of ownership… it is not in their mind how to deal with long-term values*."

The CE expert also said that the "*housing association has to become much more involved and help co-create the solution*."

Cluster – Information management

Ensuring information is shared in a transparent way was considered important by all interviewees. As the MOR representative pointed out when referring to transparent, accessible, and centralised information flows during consecutive lifecycles, *"we need building information models, with that I also need the time aspect [...] Otherwise it's not doable for anyone to keep track of all the different contracts and all the different things in there. So, you need to have a very informative model [...] over 10 years' time you want to know who delivered this, and this material, and so on […] All these kinds of things are inherited or passed on. So, it's a huge claim on information. So yes, what you need is to build a very informative database, not only material data bases will connect to it."* The same representative added on methods for sharing transparent information "*they make a very rich situation in which the owner of the building, and the municipality, and the other people are working for a future in a building. And in this case, you need this concept very much*."

The CE expert also referred to information management, especially referring to the knowledge that long-term investors like housing associations have in the whole process, including the definition of technical aspects in the project: *"we need their [housing associations'] input and knowledge and we need their honest interests."*

The CE renovation expert pointed out another aspect of information management that involves decision making about materials. "*Then there would be good databases like the Nederlands Instituut voor Bouw Biologie en Ecologie (NIBE) material database, they probably have some good ideas for you. You just have to hire them or look at their database and choose materials*."

A MOR representative also added, with reference to the importance of material databases for enabling other CE methodologies, "*what are the implications of calculating the LCA [of a material], see what is the future value of it. You do it quite explicitly as long as you know the materials coming in*."

Tools like material passports requiere sharing material composition information, allowing this information to travel with the building components through time.

Cluster – CE different and more roles

Partners in the circular project coalition should have parallel CE commitment, vision, and philosophy. According to the MOR representative, *"Basically, you are together with more or less 82 partners, and 82 is quite a lot. So, all the different departments from industry and also several private parties for instance, banks are also one of the parties in there. But also, of course, our main sponsor is from the Ministry of Internal Affairs. So, they also gave the money and put parts in, especially those elements like developing a Circular Economy idea. And the student team […] the circular economy is not that much about how you deal with the use of material but especially where you can deal with your whole building in such a situation. So, what I think is it's kind of in the building manager or property manager that was capable of bringing all these connections together."*

From the CE expert's perspective, with regards the role of the key actors in the circular way of dealing with projects, *"how different the roles of the actors are, you need to have more people*

involved […] also, having the [circular] contractor as the main role. But if they don't want to do that, then you need to have all the partners at the end of the supply chain or at the beginning. And then the different roles. So, I think mostly the contractor and its suppliers [are key actors]. So how did they see their role when they changed towards taking responsibility for a project at the end?"

Also, in the case of Noorderliefde, the government CE vision enabled the circular project to happen by implementing a law that allows the temporary adaptive reuse of vacant offices. The Eigen Haard representative mentioned that "*the leegstandswet, so if a building is empty there's a certain law […] you don't have to pay tax*." This enabled the reuse of the structure and the "slow" layers of the building.

The main contractor also had a circularity vision*, as "Etro Vastgoezorg took care of the renovation."*

However, the concept of circularity can also be misunderstood, leading to a lower degree of circularity which this document will define using the DSF. The evidence of this situation was mentioned by the Eigen Haard Representative: *"Noorderliefde is a very basic form of circular building;"* and the Noorderliefde project manager: *"The Gemeente probably will destroy this building for a big flat. So, I don't think we'll take back any of this [the building layers]. We keep the cost low, because we know it's temporary."*

The CE expert argued that all actors need to be involved in the value chain when they said that *"everybody needs to get involved with the process."*

Financial advantage

Housing associations' and pension funds' financial advantage and long-term thinking is highlighted. This can be considered in the decision-making concerning finance and cost management.

"I had to deal with different people [investors]. And some of them understand perfectly that they can be an owner while renting out, while working with clients towards an ideal situation. I did not have to deal with these very return-driven people who are not capable of doing so. So, it depends on the investor. A pension fund who is also more understanding about working for the future, while normal short-vision investors are not capable of looking beyond the home term of ownership."(MOR representative)

"In any case, housing associations do have access to very cheap money because they can get a very favourable interest rate. And if any other partner is going to do that, it's going to be more expensive. Like the only other people that can get cheap money are housing owners. Otherwise, I would say it's probably better that tenants don't lease it from a supplier. Let's say, it might also make them more vulnerable." (CE expert)

Early procurement

The importance of an early procurement of service suppliers for the CE is mentioned by the project manager of the Noorderliefde project: *"The contractor drew up a budget that was also a technical description. The installers sat at the table from the first preparations. This is a completely different way of working than we normally use. Then we made the specifications or*

technical deign together with the architect […] a 'lean' process. I've rarely seen such a rapid renovation from start to finish. Circularity was the starting point."
The CE expert also mentioned the importance of end-of-life agreements pointed out early in the process to achieve CE. *"So, you have the client and then you need a contractor, a different one, a circular contractor. Somebody that knows people at the back of the supply chain and has them involved as well, or that wants to take a different type of role in the supply chain."*

5.1.2. CE tangible resources

This business element focuses on the capability of the circular adaptive reuse firm to execute repeated actions to create material reverse cycles within the value chain. As explained in the methodology of this report, implementing consistent reverse cycles is dependent on the ability to implement CE methods and tools to this end. The following clusters can therefore be identified.

Cluster – Material circularity
This cluster is related to the Material Circularity Index, which is a tool developed by the Ellen McArthur Foundation to evaluate the material flows and processes within the value chain. *"So, M.F.A. is a methodology... Tools are like the MCI. In practice, they will always use tools. OK. If you're hiring experts, they often also use tools, but they might use the method depending on the expert."*
The awareness, methods, and tools found in the MOR, Noorderliefde, and CE experts were grouped in this cluster. This tool was specifically mentioned as being important in the MOR project, and in practice by CE experts. As a MOR representative said, *"the technical lifespan and also the functional lifespan of the product, and how much of it would be reused or refurbished, that is the MCI calculation that you can make of any product that is going into your building."*

Material reuse+ analysis
The Noorderliefde project validated this information as they were concerned with the reusability potential of materials and components, but there was no standardised tool being implemented. The Eigen Haard representative, the project manager, mentioned that *"material that could be reused we had where we could, and it had an acceptable quality in the building […] Circularity was the starting point, which means that we have tried to reuse as much material of reasonable quality as possible*."

This information was confirmed by the project leader of the Noorderliefde project, who reaffirmed the material reuse approach: *"We can make like 30 studios out of it [the former office]. Place walls and showers and stuff and offer the price really low for a mixed group of people […] We used carpets from our offices near Sloterdijk and we also have [solar] panels on the rooftop. They were from another project which didn't use the panels, so we could use them. And we the rented kitchen from Bribus. So, it's like a lease contract, they take it away in ten years and then recycle it or whatever. We also have like the sunscreens on the windows [façade], they were on the building already so we will use it again."*

The project leader added, *" there are also some parking places. They have like 15 places to put the cars and only three of the people are using them. So, the other ones we rented to people in the neighborhood."* This last quote suggests intensifying the use of an empty space. This narrows the resource loops.

5.1.3. CE design

The design business elements are related to how the firm configures a circular component or building layer during the design phase. Different design strategies were identified in practice, and classified in three clusters. These clusters indicate the degree of circularity aimed at by the design process.

Cluster – Design for closing, slowing, and narrowing the loops

In the MOR project, design for closing, slowing and narrowing the loops was achieved, as mentioned by a MOR representative: *"So, we used biodegradable materials. Yes. That was one. Everything was dismantlable. Everything was adaptable so you could change the location of different things in the prototype. That allows future flexibility of your space […] so you could adapt the space according to the layers of Brand (1995) [...] the modules we had designed were adaptable to both the needs of offices and houses. And in case one needed to be taken out, it could be done very easily. That was all taken into account by design."*

This statement shows how the design for closing and slowing the loops was present, as biodegradable and dismantlable components enable recyclability, and adaptability helps slow the loop by extending material use. The MOR representative pointed out that there were lessons learned on how to design to narrow loops, as well avoiding the use of more primary resources: *"A lesson was that what you need is much more focus for the transport parts of the building and the demountability of the building."*

This avoids the loss of material during the dismantling of components, as *"[MOR] lost quite some material in all these steps where we would have been able to bring more focus in, in a kind of exhibition approach. So, in an exhibition you make materials and rack boxes that are fairly easy to pack or take it for transport."*

As mentioned above, the adaptive reuse of the office building in the MOR and Noorderliefde projects were already slowing loops, and the design took into account the reuse of the slow parts of the building (structure and skin).

5.1.4. CE building layers

The social housing element considers what is offered to the customer. Two main clusters were defined for this element, comprised of the building layers and components. In the CE, the lifecycle and the possibility of dismantling the whole into its components and parts is important. Therefore, the following clusters emerge.

Consecutive LCA

In the MOR project, an LCA methodology was applied to ensure the parts and components of the building layers have less environmental impact, considering the whole lifecycle of each: *"The LCA calculation… that does come in on the ways of making the decision of whether, for instance, it was going to be concrete or it was going to be a wooden structure." (MOR Representative).*

"Having this building for two and a half years means that you also need to focus on the idea that [...] you can have now one function and you will have another function in a few years' time." (MOR representative).

Building components

Deconstructing the building into its parts and components is seen as necessary for implementing and assessing the amount of circularity present in the system. As the CE expert mentioned,

"what is the skin, facade? Or part floor, parts roof [...] The structure, you're talking about walls, the major openings. Those are also, again, components. And those components consist of parts. Like the insulation. It's like the heat element. The PV panels are also components. Or sub-components in that part. So, we need to choose which one you're going to tackle."

This distinction was important for the Noorderliefde and MOR projects to decide in which components or parts should have a degree of circularity implemented:

"In the end it, was a few facades, half of the ceiling plates and solar panels and bicycle racks from elsewhere. And the kitchen units were 'circularly purchased' from Bribus." (Eigen Haard Representative).

End-of-life providers

This cluster refers to assigning a service supplier in charge of taking back material and inserting it back into the economy. This activity closes the material loops for materials at the end of their lifespan. As the CE expert pointed out: "*In circularity you also often need other types of partners involved as well. So, you need to have some insight into who does things at the end of the process.*

This practice was implemented in the Noorderliefde project refering to a circular kitchen and other devices that belong to the stuff layer, as an Eigen Haard representative, the project leader, added: "*Yeah […] after 10 years Bribus take the kitchen back and recycle it or whatever. And we also have lease contracts with the washing machines; we have three washing machines and three dryers. It is the same*."

5.1.5. CE marketing

All the interviewees coincide in how promoting CE by sharing information with costumers, firms, and governments in a transparent way can help achieve CE goals. Therefore, "Information sharing and transparency in the marketing scope" is considered a cluster.

Information sharing and transparency

As the MOR project was a conceptual academic contest, there was no need to implement marketing strategies. However, the knowledge from the participants of this project was useful, as they shared their experience of the importance of marketing in implementing CE:

*"I think you can make a very rich situation in which the owner of the building, the municipality and the other people work for a future in a circular building. And in this case, you need this concept (*Van Heerde, Gijsenberg, Dekimpe, & Steenkamp*) very much. But if trust is lacking, if the story is lacking, it is not going to work at all. So basically, the problem for me is that there is no circular strategy in their thinking." (MOR representative)*

Marketing is seen as a vehicle to share CE vision with all stakeholders, as *"the nice thing about CE is that it tends to make stakeholders also understand the benefit for them." (CE expert)*

5.1.6. CE Customer relations

This business element considers the way the product and the firm relate to their customers. Firms and CE experts interviewed mentioned four main ways of relating to customers.

User participation

User participation was mentioned as a way of adding value to the offering, as customisation offers different possibilities for the customer to choose. This reciprocal relation also permits the achievement of CE and sustainability goals. User participation also becomes a criterion for

defining the target customer, as *"you need clients in the building who are convinced of key concepts" (MOR representative).*
The CE expert also found that *"the idea with circularity is, again, a main added value, a direction you could go to give users more options. So, I would always argue that it's better to do that. And in a sense, you always have to think about it with your perspective and acceptance." (CE expert)*
Thus, in the social housing sector, circularity can add value to the final product as it includes the user in the process. This adds a degree of circularity to the project, and also allows for the capturing of social value by the firm, reaching further sustainability aims:

"I just told them about the rainwater, and they want to make like a hotel for all the worms to make compost out of it. Really green mindset […] So that's what the people are doing themselves because they're responsible for everything inside the building. So, it built a community. They have to do a lot by themselves. That's how we pick those people." (Eigen Haard representative)

Adaptable
In the CE projects, adaptability, that is, the ability of a building layer or component to accommodate more than one use during a building layer's lifetime, is highlighted as being important. This was mentioned for both the MOR and Noorderliefde projects, as *"these towers can last for 100 to 200 years, so it is not much about the years on the material, but making it in a way that you can use the building in the optimal manner or for all the time, all the 200 years, and have all these different functions over time."(MOR representative)*

In the case of housing associations, "*I would say you can look at different income, like different types of business models for parts. So, for example, if you want to offer people more choices, maybe doors or something […] different options might suit best to different people; some people would stay 30 years in a house." (CE expert)*

In the Noorderliefde project, adaptable building layers were implemented, offering different uses to different customer targets during the lifecycle, as *"20 years ago, it was like an office. And it was empty for I think five years or something. And there were some startups. They just had little companies in there. And we decided 'wait, we can make like 30 studios out of it.' Place walls and showers and stuff and set the price really low for a mixed group of people."*

Flexible
Flexibility is a cluster related to the relations between the customer and unused building layers that can be rented or used by other users keeping the same use and location.

In the Noorderliefde project, this concept is applied in the site layer of the building, the parking lots, which were shared with other users from outside of the project.

In the MOR project this concept was explored considering the offices demand changing, as *"most buildings start from a single tenant office building and then you see that on very short notice they go into a multi-tenant building because the company cannot afford it, or is changing in their demand, or they will not have the whole building anymore. So, then you will have all kinds of offices with multiple tenants which requires a different office […] every tower was created in a multifunction situation." (MOR representative)*

Relocation

The concept of relocated and/or shared building layers between customers across a portfolio or from one system to another is mainly explored by the Noorderliefde project, as *"material that could be reused we had where we could, and it had an acceptable quality in the building." (Eigen Haard Representative)*

"We gave him a lot of furniture from another [Eigen Haard] project. It was for elderly people, but they didn't use the common area anymore, so we put all the stuff from there in the Noorderliefde." (Eigen Haard Representative)

5.1.7. CE social housing sector

User as a tenant and ownership as long term investment

In the social housing sector, the user as a tenant is seen as the most convenient role for the user in the circular adaptive reuse by the Eigen Haard representative, who shared that *"in this project we can keep the rent low because it's for a vulnerable group. So that's the main reason we used circularity."* The CE expert also confirmed that, "*over premises, social housing is only up for people that have low investment opportunity. So actually, it's probably better that the housing association owns them [building layers] or another stakeholder."*

Circularity stakeholder as owner

In the Noorderliefde project this procedure was found and confirmed by the interviews. A circular provider owned kitchen washing machines and dryers shifting all the CE responsibility to a specialised private party.

5.1.8. CE expenditure

LCC and LCA integration

For CE, it is important to consider the Life Cycle Cost (LCC) of consecutive lifecycles of the different building layers. This can be done by integrating the LCC and the LCA methods, as explained by the CE expert:

"This is very hard to do. So, if you start introducing methods, there will always be a slight deviation […] because it's sometimes based on different types of premises. In the end, let's say when you have an LCC, everything is in euros and the formula by which you define it, to calculate an LCC, is the net present value […] Whereas if you look at the LCA, there are some different ways you can calculate. There are different impact factors. You could measure things in. You can weight those differently. The whole thing with LCA is that you look at your product and you're trying to sort of see through the entire lifespan. Then what kind of impacts there are, and you allocate that back to your system. Whereas in the LCC the costs are only occurring in the system. And what is out there, you don't allocate to it. So, it's different."

This said the limitations for applying an LCC over consecutive LCA also requires long-term thinking with regards the key actors in the circular adaptive reuse, as shared by the MOR representative:

"The old discussion is about costs and not about values. So, they are talking about getting a certain performance already. For lowest cost. That is what they're trying to do. And so, how to deal with long-term values isn't in their mind. Although they may have a standard in need of instant flexibility, adjustability, there is no player in place who is paying that bill […] the data are still stuck in their limited concept of initial cost and then added to the cost of building and delivering it […] It can work with pension funds or housing associations if they have this intention of committing to it. Although they also have a hard time because of the low rents, the low interest to meet their own ideas, but they understand that you need to have a long-term focus in there. They are willing to make LCC that take 20 years or more into account, the demolition cost at the end of the project into account. So, for the investments to last a lifetime, and still pay as they use the building."

5.1.9. CE revenue streams

The revenue streams are a consequence of the decisions made in the value chain. In the case of circularity, the clusters defined represent two main types of pricing methods that can be applied by housing associations considering their customer target.

Product service systems

In the MOR project, the pricing methods that permitted CE were established as *"product as a service, with the possibility extend the contract at the end of the use trades, based on the contract."* In addition*, "in that case I would expect that the renting out would be done by the delivered equipment, so of course it's companies like Siemens, or those capable of doing this." (MOR representative)*

Also as mentioned before this method was implemented with the circular kitchen in the Noorderliefde project.

Diverse pricing methods

Although this PSS pricing method was used by the housing association, it is important to mention that in the case of other types of customer target, different pricing methods can lead to more options for the customer and avoid the monopoly of big companies capable of implementing PSS.

"You have to think about PSS not as the end goal, but as a product service system leasing […] then it might end up that you get a monopoly of five companies owning all of the building components in the Netherlands [….] So, what is desirable? You probably want to have some kind of diverse landscape with different options. And different options might suit best to different people." (CE expert)

"The difficulty is, of course, that you cannot get this additional quality, additional values, very easily into the combination of energy saving, and so you save on your energy bill. But it's hard to take it into account, all this kind of discussion so especially, of course, if you are renting it's difficult for corporations to claim their rents for the improvements they are doing. So basically, it was about getting a more decent business model in there. It was the intention of the MOR building as well." (MOR representative)

Material commodities

The CE expert suggested seeing the materials as transactional commodities: *"You need to have some insight into who does things at the end of the process, but also maybe partners that can supply you second-hand material. So, you need a second material broker." (CE expert)*

Sell and take back

THe CE expert in circular renovation also referencedcircular ownership transactions: “Different options might suit best to different people, some *people would stay 30 years in their house. They probably want to buy their stuff. Maybe tenants who have a short-term contract or want to stay short term in a city apartment might be more interested in leasing things […] So, in Germany the people in the kitchen, so they get a rental apartment and they put their own kitchen. And if that's this kind of modular circular kitchen that could work.” (CE expert)*

5.2. Sketching and validating a Decision Support Framework

This chapter explains how the selected set of CE methodologies implement CE principles in the value chain. Each CE method related to the business model element is characterised. Finally, the CE degree of each variable is defined using the CE measurement tool, supported by the case study interviews and literature study. This characterisation will validate the DSF.

The validation is done by comparing the CE variables found in the literature with the clusters found as an outcome of the in-depth interviews. The clusters are a practical support to the theoretical findings.

5.2.1. Characterising the CE methodologies

5.2.1.1 Adding the CE to the Project Management Body of Knowledge (PMBoK)

CE Infrastructure module /CE agreements/CE-PMBoK.

One of the most important challenges for implementing CE in the BM is related to the first business element: CE agreements. This element is closely related to the project management process, as it is the initial point that establishes the project structure and voluntary agreements between two or more actors in order to create value for the customer. Previous studies have shown that circularity in project management is one extra ambition used within the traditional manner of thinking about project management (Venselaar, 2019).

CE requires that the project management be able to bring expertise into the project from elsewhere, and that there also be room for exploration and experimentation to develop new capabilities (Venselaar, 2019). Circular projects start with the development of a circular vision, assigning importance to the clear definition of the client’s requirements, based on CE needs instead of specified requirements (Leising et al., 2018). This vision development must be established together with other stakeholders. Efficiency and transparency in information management also need to be strengthened (van den Berg, 2019). For a more detailed vision of what specific parts of the management processes need to be addressed and changed in the circular adaptive reuse, and to reveal the degree of circularity applied to a project in the BM component mentioned above, the Project Management Body of Knowledge framework developed by the Project Management Institute (2017) (PMBoK) can be used in the project coalition (Versteeg Conlledo, 2019). Some key management elements in the PMBoK were found by Versteeg Conlledo (2019) to be essential to achieving circularity within the circular project.

As indicated by the literature, six aspects of the PMBoK were modified in order to include the CE in Versteeg Conlledo’s research. These six aspects are validated by other authors, and the six of them mentioned by more than one interviewee in practice. Figure 31 shows the relationship between the six aspects mentioned in the literature, and the clusters mentioned in 5.1. Outcome of in-depth Interviews.

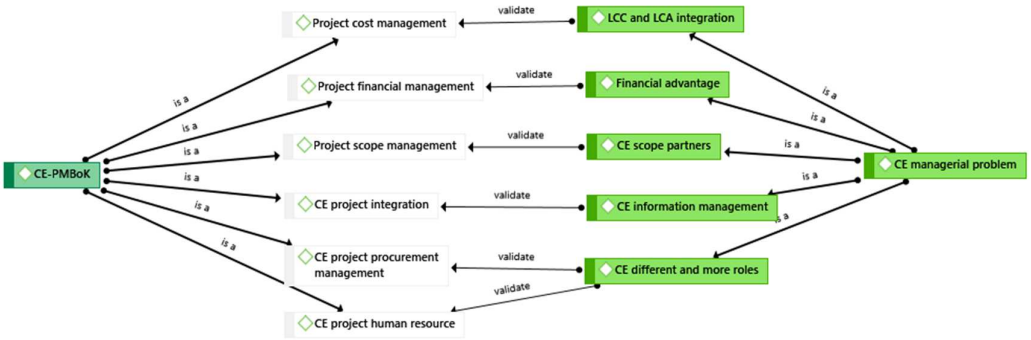

Figure 31. Relationship between business element, variables found in literature, supported by interview clusters (own work).

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The validated variables in Table 16 below are used in the DSF to explore if CE principles can be found in the CE project management. These main variables were suggested by Versteeg Conlledo (Versteeg Conlledo, 2019) and validated by other authors, as discussed in the literature review. The CE degree of the variables is high. When all or a set of variables are implemented, an environment where stakeholders can apply a broad notion of CE in the information flow is created. The application of any of the mentioned variables can lead to closing, slowing and narrowing resource loops.

Table 16. Characterisation of the CE PMBoK methodology.

CE Business sub-element	CE Method	Variable	Features	CE degree	
CE Agreements	CE PMBoK	Project scope management	Define CE **long-term** ambitions and requirements with team.	High (1)	High (6)
		Project cost management	Transparent and accessible CE budget for the team.	High (1)	
		Project procurement management	Plan tender process early in the project and involve service suppliers early in the project. Build contracts that ensure CE principles.	High (1)	
		Project integration management	Establish non-hierarchical and cooperative structures. Ensure project CE knowledge is shared in a transparent way.	High (1)	
		Project financial management	CE Responsibilities and risks shared between the parties.	High (1)	
		Project human resource	Select parties with parallel CE commitment, vision and philosophy.	High (1)	

5.2.1.2. MFA Methodology

CE Infrastructure module/CE Tangible Resources /MFA/

Implementing the MFA will allow the firm to establish goals and monitor the process from project to project, consistently ensuring circularity in the BM. However, there are still some areas of the MFA methodology that need improving: more statistics on the materials required is needed, especially for recycling and remanufacture, as is an improved identification of the material content of multi-material products. Most analyses rely on rough estimates of product lifetimes.

A tool like the MCI developed by the Ellen MacArthur foundation is used as a simplified version of the MFA directed to achieving circularity goals. To achieve the first CE principles regarding closing and slowing the resource loops, it is important to attain the recyclability, longevity, and recovery of materials in the system. To do this, the material selection is important. The Ellen MacArthur foundation developed the MCI to simplify the MFA to ease its practical implementation.

The literature and CE expert advice point to the MCI as an adequate and accessible practical tool for evaluating or applying a simplified MFA designed for CE purposes. Table 17. shows the relationship between the MFA and the MCI, and how the material circularity cluster found in all the in-depth interviews validates them.

In-depth case study interviews indicated the possibility of a new variable material reuse analysis as a non-standardised method that can be part of the main objective of an MFA and can be implemented in practice. For example, in the Noorderliefde project, the main contractor and all stakeholders explored the recyclable, reusable and intensified use potential of components without using a specific tool.

Figure 32. Relation between business element, variables found in literature supported by interview clusters (own work)

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The implementation of the MFA quantifies the environmental burden of materials. This can be an extensive process, which is difficult to implement in the adaptive reuse project. The MCI is a way of registering the burden by revealing the circularity potential of the materials and components that configure the project. Implementing the tool allows an acknowledgement of the degree of CE within the tangible resources. The MCI in the process has a high CE degree as it introduces the possibility of using recyclable, reusable, and more intensively used materials compared to a similar industry average material. These conditions close, slow, and narrows the loops respectively, scoring a high CE degree.

As mentioned before, analysing the recyclability, reusability, and the possibility of intensifying a component's use without using a standardised tool, can close, slow, and narrow resource loops.

Table 17. Characterisation of the MFA CE method.

CE Business sub-element	CE Method	Variable	Feature	CE degree	
CE Tangible Resources	MFA	MCI	Tool focused on recyclable materials and reuse of components and usage intensity.	High	High
		Material reuse+ analysis	Analysis focused on recyclable materials and reuse of components without applying a standardised tool	Medium	

5.2.1.3. Design for X

CE Infrastructure Module/ CE Design /DFX.

The Design for X (DFX) method is related to the CE degree measurement tool described in Chapter 3, where variables can close, slow, and narrow material cycles. In the DFX method, each variable taken individually has a low CE degree, but when applied together in a project, the design process gains a high CE degree (see Table 18 below).

As shown in Figure *33*, the three main DFX variables (in white) mentioned in the literature are validated by interviewees. Three clusters mentioned by more than one interviewee (in green) are associated with the three main DFX variables found in literature.

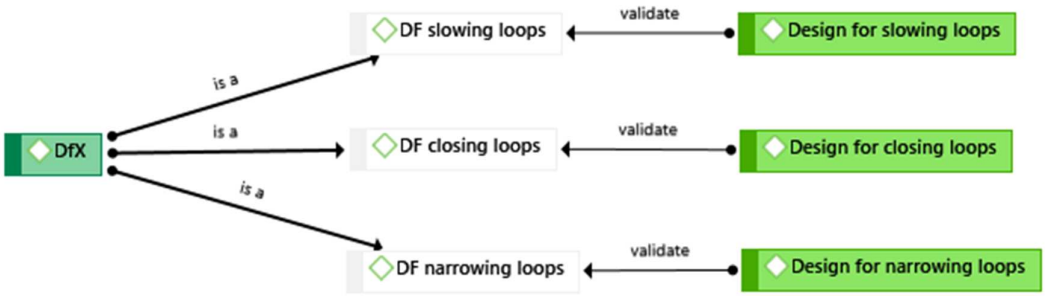

Figure 33. Relation between business element, variables found in literature supported by interview clusters (own work)

Table 18. Characterisation of the Design for x CE method.

CE Business sub-element	CE Method	Variables	Sub-Variables	CE degree	
Design	Design for X	Design for closing loops	Design for recyclability Design for energy efficiency	Low	High
		Design for slowing loops	Design for durability Design for mass customisation Design for disassembly Design for modularity MOR Design for reverse logistics	Low	
		Design for narrowing loops	Design for minimising material usage Design for remanufacturing Design for relocation	Low	

5.2.1.4. LCA methodology

CE Asset module/ CE Building Layers /LCA

In the LCA method, in-depth interviews organised in three clusters as shown in Figure 34 validate the elements found in literature and suggest one new relation with the LCA method: the cluster "end-of-life service provider."

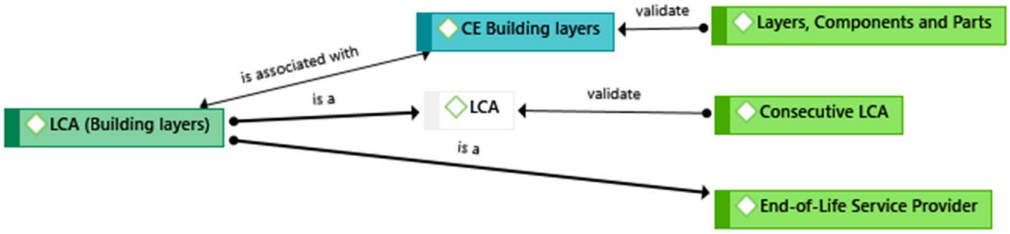

Figure 34. Relation between business element, variables found in literature supported by interview clusters (own work)

Building in layers means understanding elements as separate, with different lifespans, allowing them to be repaired or replaced or treated in different ways and at different times. The cluster "layers, components, and parts" validates the CE building layer element. The latter is used to explore the impact of CE variables on the building.

Consecutive lifecycle analyses allow the environmental burden across a multi-generational lifecycle of some building components to be defined. This suggests long-term thinking that considers different uses throughout the lifecycle of some building layers. This idea was validated by the cluster "Consecutive LCA."

In addition, the interviews suggested it is important to ensure the closing of loops, and the early assignation of a CE destination for the building layers at the end of their lifespan.

In this case, consecutive LCA can be done by analysing the adaptability of a building to different uses during its lifecycle. This activity slows and narrows resource loops, achieving a medium CE degree. The end-of-life variable suggested by the interviews is used in the DSF, closing the loops at the end of the building layer's life cycle. The end-of-life variable scores low CE degree, although when implemented with consecutive LCA, the building layers can achieve a high level of CE.

Table 19. Characterisation of the CE building layers business element.

CE Business sub-element	CE Method	Variable	Features	CE Degree	
Building layers	LCA	(consecutive) LCA	Calculate the environmental burden related to cradle-to-grave product or system at a micro level (capturing value from and monitoring less environmental burden).	Medium	High
		End-of-life service provider	Assigns the responsibility for the CE destination of the building layers and components at their end of life, to x actor.	Low	

5.2.1.5. CE promotion

CE User module / CE Marketing /CE Promotion.

Promotion of circularity is not a standardised methodology, but rather the actions concerning how the firm promotes content based on circularity within its marketing campaigns. This is important in order for the BM to capture value and communicate clear targets to the government and other stakeholders. The visibility of circularity methods to customers is fundamental to positioning the firm vis-à-vis their competitors, or to gaining value in relation to their circular reputation. On the other hand, as the MOR representative mentioned, *"I think with CE promotion you can make a very rich situation in which the owner of the building, the municipality, and all the other people are working for the same future in a building*." Thus, CE promotion works as a communication vehicle, building trust between all the stakeholders.

Figure *35* show the different variables related to the CE promotion method that involve the different possible channels of CE promotion. In green, the interview cluster "Information sharing & transparency" identifies all the variables.

Figure 35. *Relation between business element, variables found in literature supported by interview clusters (own work).*

The degree of circularity in Table 20 of the different variables of CE promotion are studied by (Chiaroni & Urbinati, 2016). The degree of circularity increases depending on the promotion scope. From individual websites with a low degree of circularity, to diverse touchpoints to communicate the circularity of the business to the different stakeholders.

Table 20.Characterisation of the marketing business element.

CE Business sub-element	CE Method	Variable	Feature	CE degree
Marketing	CE promotion	CE social media	Social media CE information	Medium-Low
		All channels	Communication through all channels	High
		CE website media	Online website Information	Low
		CE in-store communication	In-store communication through sales personnel	Medium-Low

5.2.1.6. Customisation

CE User module/CE Customer Relations/CE Customisation.

Customisation in this document is about the behaviours of the components throughout the lifecycle, in relation to the user. Customisable products intend to improve product quality considering product and component standardisation, but offering diverse options (A. van Stijn & Gruis, 2019) and adding CE to the process. All the variables gathered from the literature are validated by the interview clusters in Figure 36.

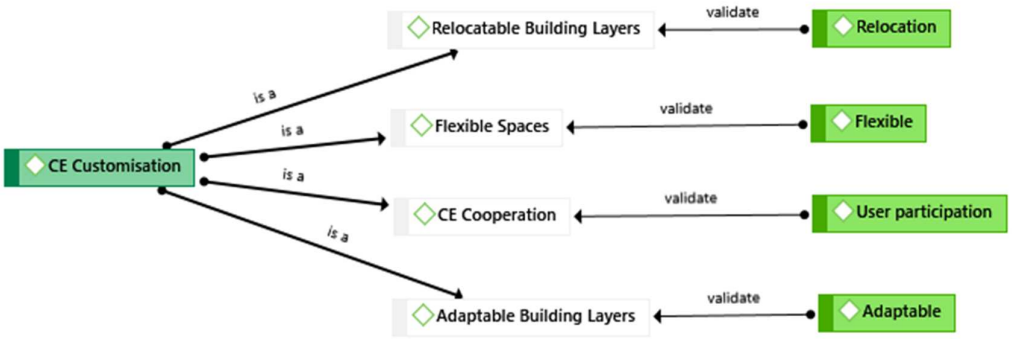

Figure 36. Relation between business element, variables found in literature supported by interview clusters (own work).

Most of the variables in Table 21. Are considered to be of a high degree of CE, as they were mentioned in literature and were present in the case studies. Figure 36. shows what variables relate to the interview clusters in green.

The CE cooperation variable is supported by users involved in closing loops by recycling water or material waste. The other variables usually manage to intensify the use of components and slow loops by extending the lifespan. If the CE cooperation variable is implemented with another variable of this element, a high degree can be achieved, if the user cooperation is directed towards closing resource loops in the same building layer.

Table 21. Characterisation of the Customer Relations business element.

CE Business sub-element	CE Method	Variable	Feature	CE degree	
Customer Relationships	Customisation	CE Cooperation	Direct cooperation of users on CE initiatives.	Low	High
		Adaptable Building Layers	Accommodate more than one use during a building layer lifetime.	Medium	
		Relocatable Building Layers	List unutilised or underused products for relocation across the portfolio.		
		Flexible Spaces	List unutilised spaces for additional renting customers.		

5.2.1.7. Social housing sector

CE Customer module/ CE Housing Sector/ CE User Characteristics

Housing associations in the Netherlands are responsible for 75% of the rented sector. The target group is mostly in the low-income sector. The user is usually a tenant. This target group is financially vulnerable, facilitating a rental relation from suppliers and opening the possibility of implementing "product as a service."

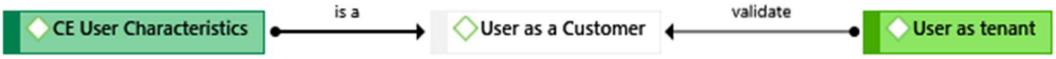

Figure 37. Relation between business element, variables found in literature supported by interview clusters (own work)

Product as a service is well known as a pricing method that enables all CE principles, it facilitates lifespan and waste control by the service providers. The social housing sector is based on rental housing. Therefore, user as tenant relation is explored and understood as a high CE degree element, as it is supported by different authors that refer to the environmental benefits of product as a service applied to a clean product, and how it can enable a high CE degree, as in the Noorderliefde kitchen.

Table 22. Characterisation of the housing sector business element.

CE Business sub-element	CE Method	Variables	Features	CE degree
Social housing sector	User characteristics	User as customer	User as a tenant	High

5.2.1.8. CE expenditures

CE Financial module/ CE Expenditures/LCC

The financial module is a consequence of the implementation of the previous business processes. The variable of the LCC method is the integration of the LCC with the LCA. Previous studies mention the concept of LCC and LCA integration without showing many solutions for implementation. LCC in literature and in practice do not usually take into account the whole lifecycle.

Integration enables the LCC to broaden the scope of analysis and take into account the long-term environmental burden in the LCC. Different authors discuss the importance of this integration as it considers the costs of closing, slowing, and narrowing the loops. In the case studies, the CE expert and the MOR representative converge in the LCC integration topic, thus validating the concept (Figure 38).

Figure 38. Relation between business element, variables found in literature supported by interview clusters (own work).

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Table 23. Characterisation of the CE expenditures business element.

CE Business sub-element	CE Method	Variable	Feature	CE degree
Expenditures	LCC	LCC - LCA	Integration of LCC with LCA.	High

5.2.1.9. Revenue streams

CE Financial module/CE Revenue Streams / CE Pricing method

The choice of pricing method will be based on a degree of circularity. In this case, product service systems (PSS) are mentioned by different authors as a pricing method related to the achievement of CE principles. Users rent instead of owning the housing and the stuff inside. In this way, long-term thinking owners can be responsible for slowing, closing, and narrowing the resource loops. Previous research shows that PSS can be beneficial when leasing is applied to a "clean" product; products that save energy in the use phase and require a high upfront investment are usually beneficial for the environment (Scheepens et al., 2016b). Thus, PSS can diminish environmental burden when all the other BM elements previously described are met to some degree. The more layers a long-term investor owns, the better for circularity.

Figure 39 shows how different variables related to CE pricing methods were found in the literature. Some of them were PSS and the diverse pricing methods cluster. The latter is a set of methods that were mentioned individually by interviewees, but not reaffirmed by a peer: sell and take-back contracts and material commodities. In the case studies, product service systems were mentioned specially in the stuff layer. Mentioning the importance of CE offering diverse pricing methods such as sale and take-back, or material commodities broadening the spectrum of CE models prevents PSS companies from creating a monopoly in the future, as mentioned by the CE expert.

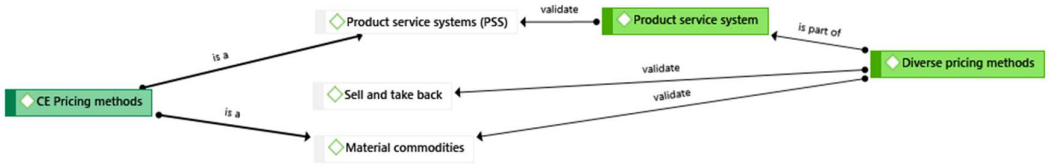

Figure 39. Relation between business element, variables found in literature supported by interview clusters (own work)

The pricing methods depicted in Table 24 are classified as high CE degree. These pricing methods allow reuse, intensify the use, and, at the end of the lifespan, are taken back by the material supplier. The latter could recycle material or reuse components where possible. This way of trading materials and building layers support the closing, slowing, and narrowing of resource loops.

Table 24.Characterisation of the revenue streams business element

CE Business sub-element	CE Method	Variables	Feature	CE priority
Revenue streams	CE pricing method	PSS	Leasing building layers	High
		Sale take back	Purchasing and giving back at the end of lifecycle	
		Material commodities	Transaction of materials in the operation phase of the project to buyers seeking to manage their position against increasingly volatile material prices	Medium

5.2.2. Validated Decision Support Framework

Based on the previous CE method characterisation, the following framework functions as an assessment scorecard to reveal the CE degree implemented in existing processes, and also to decide how or to what degree a project can be circular.

The DSF is divided into four modules that represent four key processes for adaptive reuse: infrastructure, asset, customer, and financial modules. The four modules are related to each other, they define the architecture of the adaptive reuse project's processes, and its "network of partners for creating, marketing and delivering this value and relationship capital, in order to generate profitable and sustainable revenue streams" (Osterwalder, 2004). CE methodologies, or part of them, need to be present in one or more of the modules to some degree in order to achieve circularity.

The following guides have to be followed to assess the CE degree of a circular adaptive reuse project, or to support the decisions of investors willing to set a CE degree for future projects.

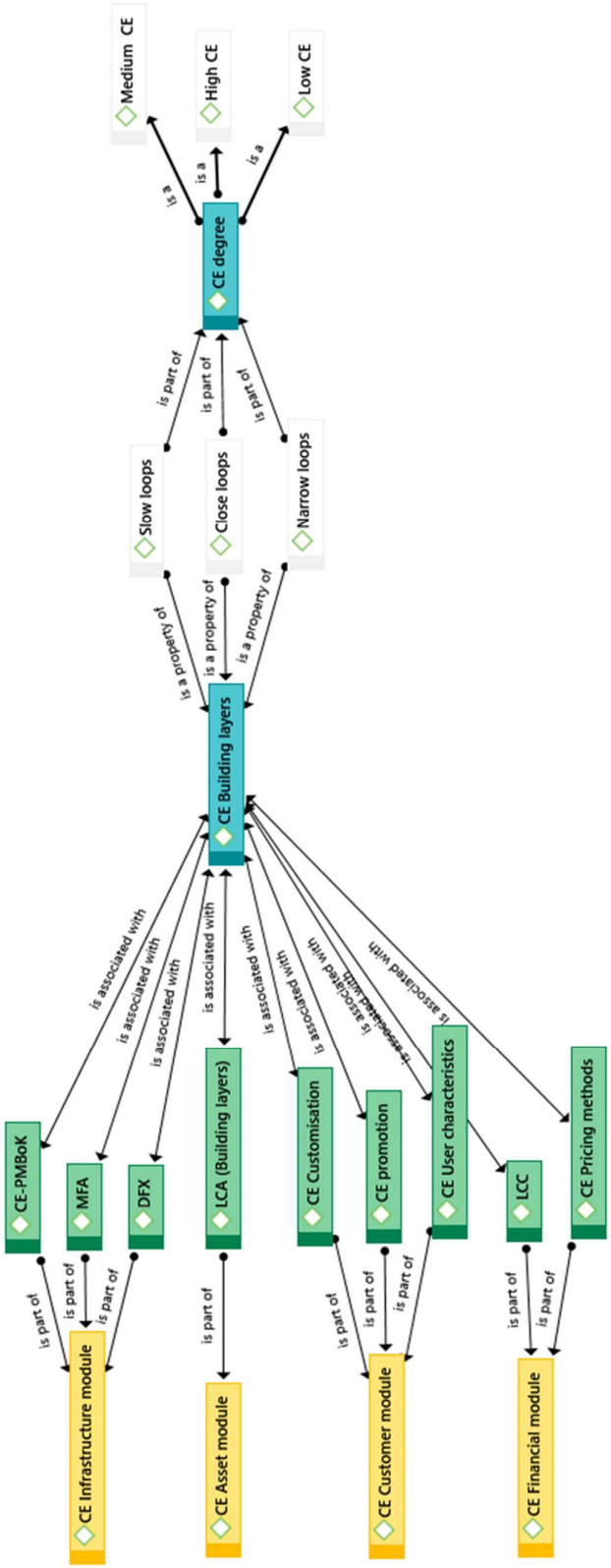

Figure 40. Overview of the Decision Support Model concepts (own work)

5.2.2.1. Asset module

The asset module is an overview of the components offered by the project. In the case of the housing associations, they configured a three-story social housing project with 33 apartments. The module evaluates if the environmental impacts of the offerings during their whole life span are mitigated by considering consecutive life uses. On the other hand, it explores if there is an assigned responsibility or process to ensure materials or components are recycled at the end of life. The module suggests identifying in what building layer these variables are considered or not. The answer can be negative or positive for each building layer. Then, the CE measurement tool is used to identify to what extent these variables close, slow or narrow resource loops.

5.2.2.1.1. CE degree asset module

In this module, the CE degree is assigned to the consecutive lifecycle analysis and recycling end-of-life variables. Buildings are usually demolished or considered expired or abandoned prematurely by investors when a use lifecycle viability is over. At this point, the slow parts in particular could still last for several more years. Consecutive lifecycle in the project implies that a building layer is being used, or conceived to be used, for more than one use cycle in its lifespan. This activity allows the use of fewer primary materials for the next project, and the extension of the use lifecycle. Meaning that this procedure allows the material loops to be slowed and narrowed. On the other hand, recycling end-of-life is a procedure that ensures that materials are being biodegraded or recycled by a circular provider, closing the material loops. These two activities are therefore complementary, and when applied together to the same layer can achieve a high level of circularity.

5.2.2.1.2. Assessment

The asset module is related to the analysis of the lifecycle of all the building layers and taking action at the end-of-life of these components. In the Noorderliefde case, the structure, skin, stuff, and site were elements that were adapted into other uses. The structure and skin of the 20-year old office were transformed into a residential building in May 2018. Nevertheless, only part of the stuff layer had a completely defined lifecycle including a circular end-of-life. The layers, service, and space plan were not adapted or reused after the first operation period, and interviews did not uncover any process considering their reuse, adaptability, or recyclability in the future. They will probably be disposed of in a way that produces waste, meaning that these building layers are not circular, and no consecutive LCA practices and end of life perspectives were found at these levels.

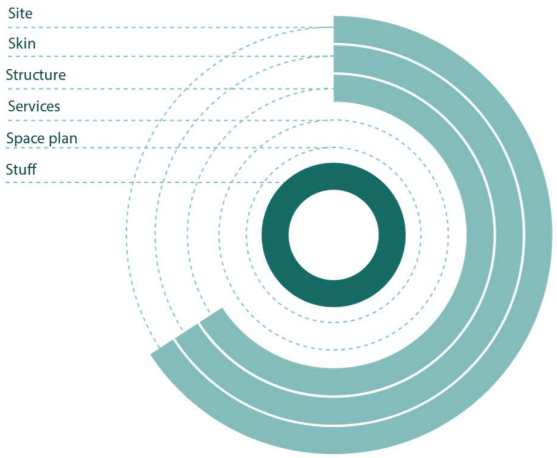

Figure 41. Results for the asset module. The site, skin and structure layers score medium, and stuff scores a high level of circularity. The bars show the amount of circularity achieved by the different building layers.

Table 25. Decision support framework asset module with Noorderliefde assessment results.

Asset module								
CE BM sub-element	CE method	Variables	Yes/ No	CE building layer	CE degree		CE building layer	Tot _CE degree
Building layers	Lifecycle analysis (LCA)	Consecutive LCA (narrow and close loops)	Yes	Structure	Medium	High	Structure	Medium
			Yes	Skin			Skin	Medium
			No	Services			Services	None
			No	Space p.			Space p.	None
			Yes	Stuff			Stuff	High
			Yes	Site			Site	Medium
		Recycling end-of-life (close loops)	No	Structure	Low			
			No	Skin				
			No	Services				
			No	Space p.				
			Yes	Stuff				
			No	Site				

In Table 25, the columns starting from 'yes/no' help determine if the variable in the previous column is applied to a building layer. Then the CE degree column indicates the impact of the variables applied. The next columns define a total CE degree for the asset module.

Figure 42 shows the layers used for the adaptive reuse project in 2018, and their lifecycle before and after the adaptation. The light green on the row for each layer are owned by Eigen Haard (the structure, skin, part of the stuff, the site – not the land but elements on the site). Only the skin, structure, part of the stuff and site consider multiple lifecycles, the former office was transformed into housing preserving these layers and part of the stuff was relocated from other projects within the portfolio. Unfortunately, there is not a clear decision on what will happen at the end-of-use of these layers. Nevertheless, another part of the stuff layer, the kitchen, washing machines, and dryer were acquired and installed after the adaptation, and provided and collected by a trustworthy circular supplier at the end of the lifespan.

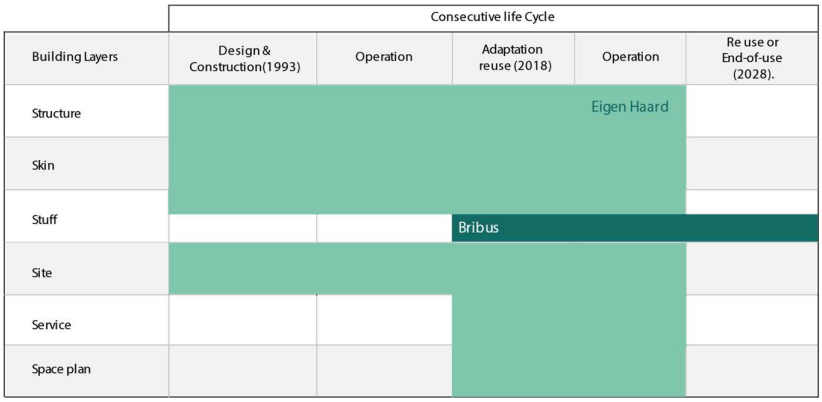

Figure 42. Life cycles of Building layers used in the adaptive reuse and its owner (own work).

Consecutive LCA & end-of-life

The **structure and skin** are designed, built, operated and then adapted and operated once more extending the life of these components. They were occupied again more intensively as a residential building 25 years after being built. There is not a clear idea about what will happen at the end-of-life with these layers.

The **stuff** used in the adaptation and the **site** are fully circular. The kitchen and washing and drying machines used in the adaptation are from reusable sources and collected by the provider at the end of use. Other parts of these layers consist of furniture relocated from underutilised projects. The furniture is reused, although there is no clear end-of-life plan for it. It is important to highlight that the ownership of this layer is shared between the long-term investor and the private party that owns the fully circular kitchen and washing and drier machines.

The **site**, like parking lots and the garden built in collaboration with the users, was a reused space from the former office. There is also uncertainty on the final destination of these materials after they are demolished.

The inner guts of the Noorderliefde building, as Brand defined **services**, and the **space plan** (walls, floors, ceilings, doors, and divisions) are newly owned by the housing corporation and installed for the adaptation by the main contractor. Unfortunately, there is not an explicit end-of-use plan for these layers after demolition.

5.2.2.1.3. Decision making

For the decision-making process, the asset module is implemented following the inverse order from the DSF assessment function. First, the user of the DSF must define what level of circularity they are willing to achieve in a three-level scale, comprised of low, medium, and high, and to what part of the building they apply. For instance, choosing high in one layer will mean that a building layer must include the two variables, if the decision is medium or low the building layer must implement one of the two variables in the process.

The decision maker can consider different variable combinations to the different layers and finally decide to what degree CE can be implemented in the project, and what procedures to implement in the process.

Table 26. Decision making matrix for CE Building Layers. The blue typography shows an example of how the module can be used by the decision maker.

Asset module								
CE BM sub-element	Tot _CE Degree	CE Building layer	CE degree		CE Building Layer	Yes/No	Variables	CE Method
CE building layers	High	Structure	High	Medium	Structure	yes	Consecutive LCA (narrow and slow loops)	Lifecycle analysis (LCA)
	Medium	Skin			Skin	yes		
	Low	Services			Services	no		
	none	Space p.			Space p.	no		
	none	Stuff			Stuff	no		
	none	Site			Site	no		
				Low	Structure	yes	Recycling end-of-life. (close loops)	
					Skin	no		
					Services	yes		
					Space p.	no		
					Stuff	no		
					Site	no		

5.2.2.2. Infrastructure module

The infrastructure module analyses if there is an implementation of CE in the network that creates value. This module is divided into two parts: information and material flows. The former explores the non-material aspects related to information and management activities, while the latter focuses on the material and spatial notions of the building.

5.2.2.2.1. CE degree infrastructure module

All of the following six variables in this module pursue a high CE in the process. The application of each of these variables implies a high circularity to the building layer involved, although the greater number of variables directed to the layers achieves greater CE confidence. The confidence levels go from one to six, with six being the total number of variables. These variables do not ensure the closing, narrowing, or slowing of the loops, but build a robust information network directed towards a CE vison and philosophy in the infrastructure process.

In the second part (material flows) the material circularity index (MCI) and the reusable+ variables are a way to monitor the material flow at different degrees. The MCI allows the analysis of the circularity potential of material used in the project. This procedure ensures that material flows are made by recycling, reusing, and manufacturing to intensify use and avoid the consumption of primary materials in the future. This tool can be applied to achieve fully circular layers. On the other hand, the reuse+ variable is a less rigorous non-standardised procedure where there is not much information on the materials' biodegradability or recyclability, but there is a qualitative approach to assess which parts can be reused for a new function. This allows the narrowing and slowing of material loops. When the two variables are applied or the MCI is implemented to the a layer a high circularity degree is achieved.

In the design process, the module analyses if closing, narrowing, and slowing of loops is considered in the design of the building layers. This part of the DSF used the same logic as the CE measurement tool described in Section 3. Each of the procedures for closing, narrowing, or slowing loops defined previously in this document, have a low degree of circularity; if two of them are applied to a layer then a medium degree of CE can be achieved, and if the three procedures are applied then the layer will have a high degree of CE.

The results of the material flow analysis and the design are compared, and the highest score is taken into consideration as an overall result for the module.

5.2.2.2.2. Assessment I (information flows)

The information flow considers the non-spatial (Winch, 2009) or non-material aspects of the process; it is about the flow of information in terms of infrastructure, which allows the project to happen. It focuses on assessing how CE performs in the infrastructure and logistical levels, with what kind of partners and network the decision maker is establishing partnerships for CE achievement.

The information module involves the arrangement of partnerships between parties, activities, and resources that close, slow, or narrow material loops, and the ability to execute these activities in a consistent way.

In the Noorderliefde project, three variables were found: (1) CE project scope management, (2) CE procurements management, and (3) CE project human resource.

Eigen Haard, and the main contractor Etro, managed to adapt and reuse the former office building as housing, thus extending its use lifespan. It was in the long-term scope that Eigen Haard decided to adapt the structure and skin into housing, with the help of a “circular” main contractor. With regards the stuff layer, another key actor appeared. A circular supplier was supplied elements of the stuff layer: the kitchen, washing machines, and dryers. All the actors were included early in the process and circular contracts were acquired from Bribus. All main stakeholders shared a CE vision and philosophy. The process had a very practical approach and as the project manager said, it was “a 'lean' process. I’ve rarely seen such a rapid renovation from start to finish.”

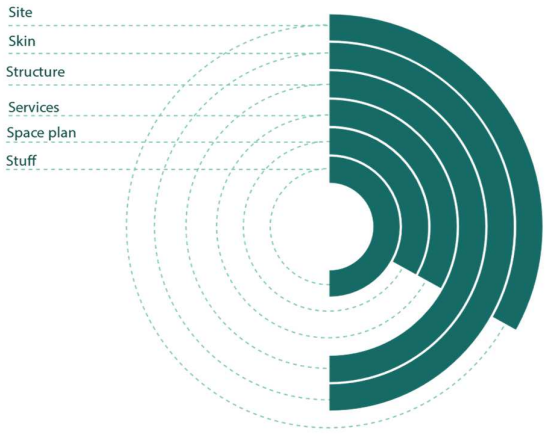

Figure 43. Results for the Information module assessment to the Noorderliefde project.

Table 27 shows the assessment of the Noorderliefde project. The six variables were tested. Where the answer is no, this is because the topic was not mentioned in the interviews and is considered absent in the process.

Table 27. Decision support framework infrastructure module (information flows) with Noorderliefde results.

Infrastructure Module (information flows).							
CE BM sub-element	CE methods	Variables (tools)	Yes/No	CE building layer	CE degree	CE layers	Total CE degree
CE agreements	CE-PMBOK.	CE project long-term scope (long term ambitions and regulations with team)	Yes	Structure	High	Structure	High (3)
			Yes	Skin			
			No	Space plan			
			Yes	Stuff			
			No	Services			
			No	Site			
		CE project cost management (accessible budget for CE)	No	Structure	High	Skin	High (3)
				Skin			
				Space plan			
				Stuff			
				Services			
				Site			
		CE project procurement management (CE suppliers early in tender process; CE contracts)	Yes	Structure	High	Space plan	High (2)
				Skin			
				Space plan			
				Stuff			
				Services			
				Site			
		CE project integration management (knowledge sharing structures)	No	Structure	High	Stuff	High (3)
				Skin			
				Space plan			
				Stuff			
				Services			
				Site			
		CE project human resource (shared CE vision)	Yes	Structure	High	Service	High (2)
				Skin			
				Space plan			
				Stuff			
				Services			
				Site			
		Financial management (risks shared between parties)	No	Structure	High	Site	High (2)
				Skin			
				Space plan			
				Stuff			
				Services			
				Site			

CE project long-term scope

The scope applied in the Noorderliefde project was directed towards reusing existing material. This strategy mostly affects the structure and skin. On the other hand, the ambitions and relationship built with the circular furniture supplier includes the stuff layer in the CE long-term scope variable too.

CE project cost management

A budget assigned specifically for CE was not mentioned in the study. There was only an aim to save resources by reusing material as much as possible, and not a budget for CE strategies.

CE project procurement management
This variable was very important for the whole project. The service suppliers were all involved from when the first preparations were made, working together in a completely different way to how they usually work.

CE project integration management
Working closer from the beginning, all actors shared more information at earlier points in the process, but no specific initiative to foster information sharing was pointed out.

CE project human resource
The Noorderliefde project included service providers aligned with the CE.

CE financial management
No type of risk-sharing structure was mentioned between service providers or clients, different to the usual risk distribution observed in a traditional non-circular project. Special taxing procedures by the government directed to social housing are not considered.

5.2.2.2.3. Assessment II (material flows)
The material module covers two processes: CE tangible resources and CE design. One is focused on materials and the other on design parameters. This module involves the cause and effect of the material flow of the project. It explores the act of conceiving the materiality and the material itself.

In the Noorderliefde case study, no material flow analysis or MCI was found. The amount of material recycled or reused is uncertain, except for part of the stuff layer, which was outsourced to a reliable circular supplier capable of implementing an MFA or MCI to their circular kitchen. However, there is also a non-standardised practice based on practice and experience to determine the structure's and the skin's reusability.

The structure and the skin were preserved for the adaptation as much as possible, though some tiles needed replacement. The durability of these two layers help to slow the loops. With regards the design for x procedure, the kitchen is the only element that is conceived of as closing, narrowing, and slowing the loops by a circular supplier. Figure 44 below shows the results for the material module.

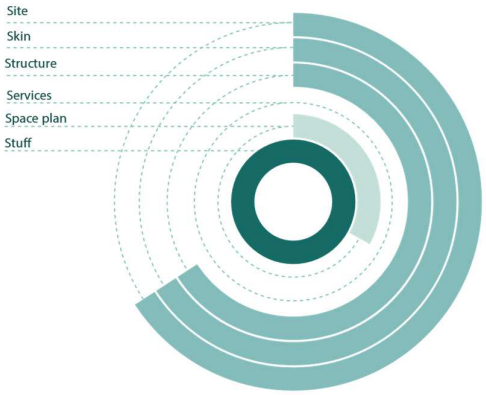

Figure 44. Results for the infrastructure module (material flows). Site, skin and structure layers score medium and stuff scores a high level of circularity.

The following table is the matrix to assess the project's material processes. It starts by exploring if there is a method or variable (in the table: yes/no) implemented to any of the CE building layers. Then the CE degree column determines the impact of the procedure on the building layer. Finally, the last two columns add the impacts and gives a total degree of circularity for the material module.

Table 28. Decision support framework material module with Noorderliefde assessment results.

Infrastructure module (material flows)								
CE BM sub-element	CE Methods	Variables (tools)	Yes/No	CE building layer	CE degree		CE layers	Total CE degree
CE tangible resources	Material flow analysis	Material circularity index (MCI)	No	Structure	High	High	Structure	Medium
			No	Skin				
			No	Space p.				
			Yes	Stuff				
			No	Services				
			No	Site			Skin	Medium
		Reusable+ material analysis	Yes	Structure	Medium			
			Yes	Skin				
			No	Space plan				
			Yes	Stuff				
			No	Services				
			Yes	Site			Space plan	Low
CE design	Design for x	Design for narrowing resource loops	No	Structure	Low	High		
			No	Skin				
			Yes	Space plan				
			Yes	Stuff			Stuff	High
			No	Services				
			No	Site				
		Design for slowing resource loops	Yes	Structure	Low			
			Yes	Skin				
			No	Space plan				
			Yes	Stuff			Services	None
			No	Services				
			Yes	Site				
		Design for closing resource loops	No	Structure	Low			
			No	Skin				
			No	Space plan				
			Yes	Stuff			Site	Medium
			No	Services				
			No	Site				

Material Circularity Index

A Material Circularity Index was not used, and much less a material flow analysis (MFA). The latter is a specialised, standardised methodology, and the former a simplified form of the MFA that is more commonly used in practice because it is not as complex to implement. Nevertheless, none of these tools were found in most of the layers. However, it is assumed that a form of these variables is applied to the circular kitchen by the circular provider.

Reusable+ material analysis

There was a non-standardised approach towards the reuse (slow loops) of materials to extend their life and intensify their use in the Noorderliefde project. The structure and the skin were considered to be reused for 10 more years, intensifying their use by responding to a social residential need. Eigen Haard also listed underutilised furniture and relocated it to the Noorderliefde, and the reused parking lots in the site are shared with other users from outside the project.

Design for closing, slowing and narrowing the loops.

The layers assessed in this part are the ones that were designed for the adaptation. The reused layers like skin, site, and structure were not designed for the CE.
From all the elements, the only evidence of a layer designed using the three CE principles is part of the stuff layer. The kitchen is fully circular and supplied by a private party.

1. **Design for closing loops**
   As mentioned before, only the stuff layer was designed with recyclable parts and materials by the circular provider. Recycling materials was not considered for the other layers.
2. **Design for slowing loops**
   In the design process, the structure, skin, and the site were considered to be reused. The other layers, the "fast" ones, were distributed in the project fulfilling that objective, but they were not designed to be reused or adapted after the operation phase.
3. **Design for narrowing the loops**
   The circular kitchen designs foster a more intensive use of the components and less use of primary resources. The space plan design also considers the old structure and reusable parts, allowing a reduced consumption of primary materials in the manufacturing of the parts that compose this layer.

5.2.2.2.4. Decision making

To implement this module for decision making, the decision maker should know that any variable applicable in this module will deliver a high CE but, in this case, more is more. Adding more variables to a layer ensures a proper foundation for the CE project.

For decision making, Table 29 is read and filled from the right to left. The table is a fragment of Table 27. To illustrate the procedure, first the decision maker defines what kind of measures they are willing to pursue for the different layers, knowing that the more layers and variables involved, the better the environment for the CE development.

Table 29. Fragment of the infrastructure module (information flows) DSF. The text in blue shows an example of how the module can be used by the decision maker.

Infrastructure module (Information flow).							
CE BM sub-element	Total CE degree	CE layers	CE degree	CE building layer	Yes/No	Variables	CE method
CE agreements	High (2)	Structure	High	Structure	yes	CE project long-term scope (long term ambitions and regulations with team)	CE-PMBOK
				Skin	yes		
	High (1)	Skin		Space plan	no		
				Stuff	no		
	None	Space plan		Services	no		
				Site	no		
	High (1)	Stuff	High	Structure	yes	CE project cost management (accessible Budget for CE)	
				Skin	no		
	None	Services		Space plan	no		
				Stuff	yes		
	None	Site		Services	no		
				Site	no		

In the second part, the decision maker must decide the total CE degree they are willing to apply to the different layers. The table below shows a fragment of the Table 28, adapted to illustrate how the material module can be used for decision making. After choosing the total degree they are willing to apply in the building layer, the decision maker then uses the CE degree yes/no column to decide what variables or methods can be implemented in the project to achieve the desired circularity in the material processes.

Table 30. Fragment of the material model DSF. The text in blue shows an example of how the module can be used by the decision maker.

Infrastructure module (Material flows).							
CE BM sub-element	Total CE degree	CE layers	CE degree		CE Building Layer	Yes/No	Variables	CE method
CE Tangible resources	High	Structure	High	High	Structure	yes	Material circularity index (MCI).	Material Flow Analysis.
					Skin	no		
	Medium	Skin			Space p.	no		
					Stuff	no		
	None	Space p.			Services	no		
					Site	no		
	None	Stuff		Medium	Structure	no	Reusable+ material analysis.	
					Skin	yes		
	None	Services			Space p.	no		
					Stuff	no		
	None	Site			Services	no		
					Site	no		

5.2.2.3. Customer module.

Customer interface is divided into two parts. A non-spatial and one that impacts on the spatial conditions of the building, affecting the building layers directly; this shows how CE is promoted and how the users and other actors get in touch with the circular concept of the project: (1) it defines a segment of customers, (2) how the company gets in touch with them, and (3) what media the firm uses to get in touch with them. The second part goes further, exploring how the building layers interact with the users, what interface is used, and how the building layers use CE to cope with changing demand.

5.2.2.4.1 CE degree customer module

The first part of this module has two subsections, the promotion aspect related to CE marketing and the Housing sector customer characteristics. In the first one, contemporary online social media channels and publications by journals or magazines are considered a medium CE degree as they are tools with a strong potential to reach more people than in-store communication and private client's websites. All the options are complementary and can determine a high CE degree when applied all together. The second subsection is related to the user characteristics, and previous chapters have mentioned the lack of diverse exploration of CE behaviours and characteristics, apart from the user-as-tenant relationship with regards products as services. Therefore, user-as-tenant is considered to have a high degree of CE, as it is a good mechanism for closing, narrowing, and slowing loops. In addition to this subsection, evidence from Noorderliefde confirms Eigen Haard's long-term ownership of some layers, which enabled the adaptive reuse of the former office. In this way, it can be said that a long-term investor as owner of the building layers helps to extend the lifecycle of the building by slowing and narrowing resource loops.

5.2.2.4.2. Assessment part I (information flows)

For the assessment of the first part of the module, Table 31 is used. This table has two sub-sections that are assessed independently. The CE promotion refers to all layers and is used to evaluate how the CE project information gets in touch with the costumers. Each variable in this section has a CE degree value on its own, and achieving all is considered a CE high degree.

The second sub-section evaluates the degree of CE related with the housing sector and user characteristics. In the case of the Noorderliefde, a social housing project, all the layers were rented by the users. There were variations on the actors owning these layers. The degree of CE according to the user characteristics reveal the topic of ownership as an important matter to assign or explore CE responsibilities.

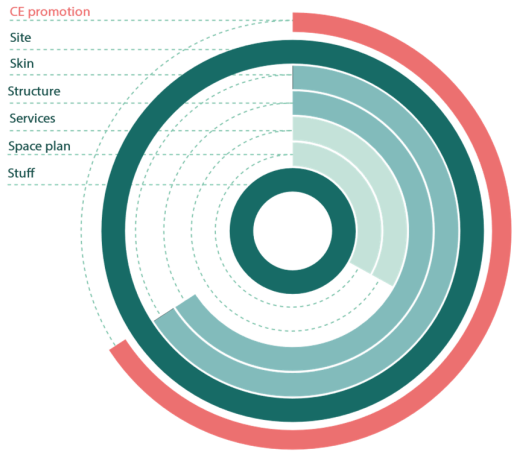

Figure 45. Results customer module I (information flow). In red is the CE promotion in the marketing & media processes.

Table 31. Decision support framework customer interface module with Noorderliefde results.

Customer module (information flow)								
CE BM sub-element	CE Method	Variables	Yes / No	CE building layer	CE degree		Building layers	Total CE degree
Sub-section 1								
Marketing & media	CE promotion channels	CE social media	No	All	Medium	High	All	Medium
		CE publications	Yes		Medium			
		CE website media	Yes		Low			
		CE in-store communication	No		Low			
Sub-section 2								
Housing sector	Customer characteristics	User as owner	No	Structure	Low	Low	Structure	Medium
				Skin				
				Space plan				
				Service				
				Site			Skin	Medium
				Stuff				
		User as customer	Yes	Structure	Low	High		
				Skin				
				Space plan			Space plan	Low
				Services				
				Site				
				Stuff				
		Ownership as long-term investment	Yes	Structure	Medium		Services	Low
			Yes	Skin				
			No	Space plan				
			No	Services				
			Yes	Stuff			Stuff	High
			Yes	Site				
		A circular stakeholder as owner	No	Structure	High			
			No	Skin				
			No	Space plan			Site	High
			No	Services				
			Yes	Stuff				
			Yes	Site				

According to Table 31, marketing and media have four variables: social media, publications, website, and in-store communications channels to communicate CE information related to the project. Each variable has a CE impact, as shown in Table 31. The fulfilment of all variables means a high CE degree in the marketing process.

The second sub-section focuses on the four variables:

User as owner

In the CE field, the customer-as-owner of products is not explored as much as products as services. It therefore has a low CE degree in this literature, although further research on this topic is required. As the target group of the Noorderliefde project is the social sector, users are usually tenants and do not own the building layers.

User as customer

In the literature, user-as-tenant is the perfect fit for product-as-service systems is well-known in the CE field. Services have the benefit of making the owner responsible for extending the life (slowing the loops) of the product-as-service, although this does not ensure the closing and narrowing of loops**.** Customer-as-tenant is the user characteristic of the social sector.

Ownership as long-term investment

If the user does not own the building layers, who does? Research on adaptive reuse shows how long-term investors are more likely to invest in transformations or activities that include slowing loops and reusing material or intensifying the use of buildings (narrowing loops). Thus, this variable is considered to have a medium degree of CE. Ownership as a long-term investor does not guarantee closing the loops at the building layer's end-of-life.

In the Noorderliefde project, the slow layers structure and skin are considered a long-term investment as it has been used for a long time (25 years). The circular kitchens, part of the stuff layers, are also owned as a long-term investment by a long-term thinking private organisation.

The site is owned by the government as a long-term investment for the city. In contrast, the service plan and services are not seen as a long-term investment, but rather as layers built for only 10 years' operation.

Circular stakeholder as owner

The ownership of elements by a reliable circular organisation means that the building layer will be treated according to all the knowledge that the CE imply. Thus, the DSF gives this variable a high degree of CE. In Noorderliefde, the kitchens were owned by a circular supplier and the site is owned by the municipality of Rotterdam, which promotes the CE.

5.2.2.4.3. Assessment part II (material flows)

The second part of this module explores how the building layers interact with the customer. Figure 46 shows the results of this part of the module where the structure, skin, and site scored medium, and the stuff high. As in other modules, a CE degree was not identified in the space plan and services layers.

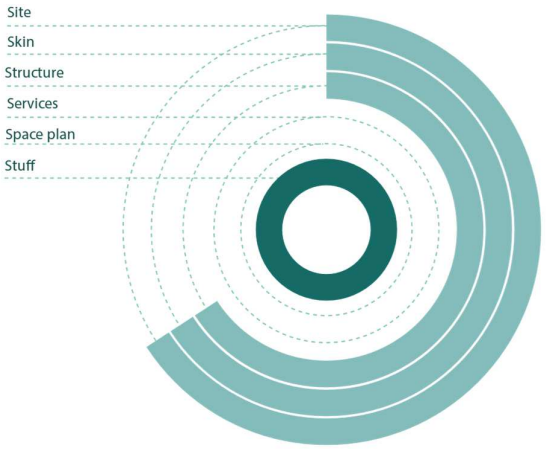

Figure 46. Results Customer module second part (material flows).

The matrix applied to the output shown in the figure above is built with the main logic of the other modules. As shown in Table 32, the first step identifies if there is (yes/no) a variable or

variables applied in the different building layer customisation processes. If there are any, then the CE degree column will help determine the CE impact on the building layer.

Table 32. Customer module DSF (material flow) with Noorderliefde results.

Customer Interface module (material flow)								
CE BM sub-element	CE method	Variables	Yes / No	To which building layers?	CE degree		CE layer	Total CE degree
Customer relationships	Customisation	CE cooperation	No	Structure	Medium-High	High	Structure	Medium
				Skin				
				Space p.				
				Services				
				Stuff				
				Site			Skin	Medium
		Adaptable building layers	yes	Structure	Medium			
			yes	Skin				
			No	Space p.				
			No	Services				
			No	Stuff				
			yes	Site			Space p.	None
		Relocatable building layers	No	Structure	Medium			
			No	Skin				
			No	Space p.				
			No	Services				
			yes	Stuff				
			No	Site			Services	None
		Flexible building layers	No	Structure	Medium			
			No	Skin				
			No	Space p.				
			No	Services				
			yes	Stuff				
			yes	Site			Stuff	High
		Recyclable Building layers	No	Structure	Low			
			No	Skin				
			No	Space p.				
			No	Services				
			Yes	Stuff				
			No	Site			Site	Medium

CE cooperation

CE cooperation is the first variable that indicates user participation in CE procedures. This could be, for instance, maintaining an aquaponics system, as mentioned by one MOR representative. This kind of user involvement in the Noorderliefde was attempted by building a water recycling system, but it was never completed. Thus, this variable was not present within the building layers.

Adaptable building layers

These are building layers that accommodate more than one use in a lifetime, in the same location. This confirms and validates the idea of consecutive LCA in the asset module. In the Noorderliefde project, only the structure, skin, site, and stuff were considered. The structure, skin, and site were used as an office 25 years ago, became vacant after 10 operation years, and were converted to residential use in 2018.

The other layers were designed and operated for the same use.

Relocatable building layers

This practice lists underutilised building layers for relocation within the portfolio. In the Noorderliefde case, the furniture in the common areas and rooms came from underutilised spaces at other projects managed by Eigen Haard. The other layers were operationalised in the location where they had always been installed.

Recyclable building layers

This variable closes the material loops. It is about layers made of recyclable components and materials at the end of life. In the Noorderliefde, the circular kitchen will be taken back by a circular provider at the end of the operation. The end-of-life of the other layers is uncertain at the moment.

5.2.2.4.4. Decision making

There are two parts to the decision-making process in the customer module:

The first part is related with information flows and has two sub-sections: marketing and media, and housing sector's customer characteristics. In the first one, the decision maker will decide to what degree the information concerning circularity is spread to the customers. This concerns all building layers and depends on the choice of different procedures recommended by the DFS. The second sub-section works in a similar way, with the only difference being that the CE degree is specified for each of the building layers. A fragment of the DSF matrix is provided in Table 33.

Table 33. DSF Customer module I fragment. The blue typography shows an example of how the module can be filled.

Customer module (information flows).								
CE BM sub-element	Tot _CE Degree	CE Building layer	CE degree		CE Building Layer	Yes/ No	Variables	CE Method
Sub-section 1								
Marketing and media	High	All	High	Medium	All	yes	CE social media	Marketing and media
				Medium		yes	CE publications	
				Low		yes	CE website	
				Low		yes	CE instore communication	
Sub-section 2								
Housing sector	High	Structure	Low	high	Structure	yes	User as customer	Customer characteristics
					Skin	yes		
	Low	Skin			Space plan	No		
					Stuff	No		
	Medium	Space p.			Services	No		
					Site	no		
	High	Stuff	Medium		Structure	yes	Ownership as long term investment	
					Skin	no		
	None	Services			Space plan	yes		
					Stuff	no		
	None	Site			Services	No		
					Site	no		

The second part of the customer module is related to the material flows of the building layers in relation with the user's demand. This matrix is again depicted in

Table 34.

Table 34. Decision support model (DSF) Customer module (material flow).

Customer module (material flows).								
CE BM sub-element	Total CE degree	CE building layer	Variables		CE building layer	Yes/No	Variables	CE method
Customer relationships	High	Structure	High	Medium	Structure	yes	Flexible building layers	CE customisation
					Skin	no		
	Low	Skin			Services	yes		
					Space p.	no		
	Medium	Services			Stuff	no		
					Site	none		
	None	Space p.		Low	Structure	yes	Recyclable building layers	
					Skin	yes		
	Low	Stuff			Services	no		
					Space p.	no		
	None	Site			Stuff	low		
					Site	no		

5.2.2.4. Financial module

The financial module evaluates two main things: how circularity takes part in the calculation of the expenditures, and the project's revenue streams. This is how the firm is implementing CE methods in the cost structure and the revenue model.

5.2.2.5.1 CE degree financial module

The financial module considers the expenditure accounting methods and the pricing method through which the model revenues are received. For the expenditure accounting, the integration of LCC and LCA is suggested as a high CE degree alternative mentioned by various authors and the CE expert consulted during the interview process. This alternative includes considering the environmental impacts in the expenses accounting throughout the lifecycle. Product service systems and buy- and take-back systems allow circularity third parties to be responsible for dealing with material for slowing, narrowing, and closing the loops. The last procedure involves the material commodities that allow the material transactions at the operation stage. This procedure is aligned with the idea of understanding building layers as assets that in the long term can help investors position themselves in a volatile material market. The impact of this procedure implies a long-term ownership that enables the extension of building layers, and the use of less material, as far as possible. Nevertheless, this procedure does not ensure working with biodegradable or recyclable components at the lifespan end-of-life.

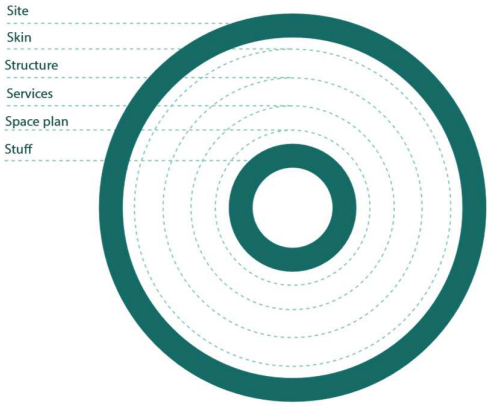

Figure 47.Noorderliefde results financial module.

5.2.2.5.2. Assessment

Table 35 shows the matrix used to assess a project's CE financial processes.

Table 35. DSF financial module with Noorderliefde results.

Financial module							
CE BM sub-element	CE method	Variables	Yes / No	To what building layers?	Ce degree	CE building layers	Total CE degree
Expenditures	LCC	Lifecycle costing LCC - LCA	No	Structure	High	Structure	None
			No	Skin			
			No	Space p.			
			No	Services		Skin	None
			Yes	Stuff			
			No	Site			
Revenue streams	Pricing methods	Product service systems (PSS) of "clean" products	Yes	Structure	High		
			Yes	Skin			
			No	Space p.		Space p.	None
			No	Services			
			Yes	Stuff			
			Yes	Site			
		Buy- and take-back	No	Structure		Services	None
			No	Skin			
			No	Space p.			
			No	Services			
			No	Stuff		Stuff	High
			No	Site			
		Material commodities	No	Structure	Medium		
			No	Skin			
			No	Space p.		Site	High
			No	Services			
			No	Stuff			
			No	Site			

In Table 35, the answer to the yes/no column has to be based on an analysis of whether any of the variables mentioned are present. Each of the variables scored different CE degrees.

Lifecycle costing – LCC

Integrating the LCC and LCA is not a simple procedure and a certain amount of information is needed in advance. This was not implemented in any way in the Noorderliefde project. The

implementation of this integration would allow the financial expenses caused by the environmental burden of a project's life cycle to be taken into account.

PSS of "clean" products

In the Noorderliefde project, there was no evaluation of the clean degree of the building's layers. Therefore, is not possible to determine if all the building layers, as a service offered by Eigen Haard, involve clean products. Only the kitchens are considered clean products, as they are supplied by a reliable circular actor. The kitchen is rented by the investor as a service for the users, so this layer scores a high degree. Although the structure and skin can be considered clean products because of the investment in durable materials that can lower the eco-cost per euro ratio, the waste in the demolition remain uncertain. In consequence, the finance element cannot be considered circular for these elements. On the other hand, the site is considered circular as it will be readapted and reused in the future, and the environmental impact is considered low.

Buy- and take-back products

In the Noorderliefde project, no layer was purchased.

Material commodities

In Noorderliefde, no initiative was implemented to include the transaction of materials within the operation period to material brokers or suppliers looking to manage their position against volatile material prices.

5.2.2.5.3. Decision making

As in previous modules, the decision maker decides to what degree CE is applied to the building layers and what procedure is required to achieve the desired CE degree.

Table 36. DSF financial module fragment.

Financial module							
CE BM sub-element	Total CE degree	CE building layer	CE degree	CE building layer	Yes/No	Variables	CE method
Expenditures		Structure	High	Structure		LCC -LCA integration	LCC
				Skin			
		Skin		Services			
				Space p.			
		Services		Stuff			
				Site			
Revenue streams		Space p.		Structure		PSS "clean" products	CE pricing methods
				Skin			
		Stuff		Services			
				Space p.			
		Site		Stuff			
				Site			

5.2.3. Noorderliefde summary results

Although the scope and the partnerships of the main actor are related to the CE, the Noorderliefde project manager indicated that it was "a very basic form of circular building." The results of the assessment try to explain what CE degree was achieved in the project.

In order to achieve circularity, a large part of all CE practices should be present is some way in the value chain. In the Noorderliefde project, some CE procedures were applied on the building layers and in all processes as shown in Figure 48.

The building layers that have a high medium and low CE degree in each module are depicted in darkest, medium and lightest colour respectively. Figure 48 shows a snapshot of how the adaptive reuse project is approached from different perspectives: asset, customer interface, infrastructure, and financial aspects. The circular bars portray the distance left to achieve a fully circular and self-sustaining economy in the project. The building layers in the image can be read in each set of rings from the outside to the inside in the following order: site, skin, structure, services, space plan, and stuff. The red ring in the customer module (information flow) represents the CE promotion aspect.

Figure 48. Summary of Noorderliefde project CE results.

5.2.4. DSF summarised elements

Table 37 is a summary of the different modules, CE BM sub-elements, CE methods, and all the variables used in the DSF. These variables were defined as a result of the literature review and in-depth interviews carried out in the two case studies. The degree of CE was defined by analysing the potential each procedure has to close, slow, and narrow resource loops. These analyses were done by different authors, case studies and CE expert interviews, using the CE measurement tool defined in this research.

Table 37. Summary of modules, CE sub-elements, CE methods, and validated variables used in the DSF.

CE modules	CE BM sub-elements	CE methods	Variables	CE degree	Total_CE Degree
CE infrastructure module	CE agreements	CE-PMBoK	CE project long-term scope	High	High (6)
			CE project cost management	High	
			CE project procurement management	High	
			CE project integration management	High	
			CE project human resource	High	
			Financial management	High	
	CE tangible resources	MFA	Material circularity index. (MCI)	High	High
			Reusable+ material analysis	Medium	
	CE design	Design for x	Design for narrowing loops	Low	High
			Design for slowing loops	Low	
			Design for closing loops	Low	
CE Asset module	CE building layers	LCA	Consecutive LCA	Medium	High
			Recycling end-of-life	Low	
CE Customer module	CE marketing	CE promotion	CE social media	Medium	High
			CE publications	Medium	
			CE website media	Low	
			CE in-store communication	Low	
	CE housing sector	CE user characteristics	User as owner	Low	Low
			User as customer	Low	High
			Ownership as long-term investment	Medium	
			Circular stakeholder as owner	High	
	CE customer characteristics	CE customisation	CE cooperation	Medium-High	High
			Adaptable building layers	Medium	
			Relocatable building layers	Medium	
			Flexible building layers	Medium	

			Recyclable building layers	Low	
Financial module	CE expenditure	LCC	Lifecycle costing LCC - LCA	High	High
	CE revenue streams	Pricing methods	Product service systems (PSS) of “clean” products	High	High
			Buy- and take-back	High	
			Material commodities	Medium	Medium

06

Recommendations

6. Recommendations

In this chapter, drawing form the CE achievements of Eigen Haard in the Noorderliefde project, two business models are defined as recommendations for the improvement of circularity in the adaptive reuse process enabled by housing associations. These models consider the methods applied to fully circular building layers as examples that can be applied to other layers, and analyses the CE methods that shorten the remaining distance required for CE layers with a low or medium degree of circularity to achieve fully circularity. This chapter will use Noorderliefde project CE degree snapshot defined in Chapter 5 to build procedures for housing associations to implement in order to achieve a CE adaptive reuse project.

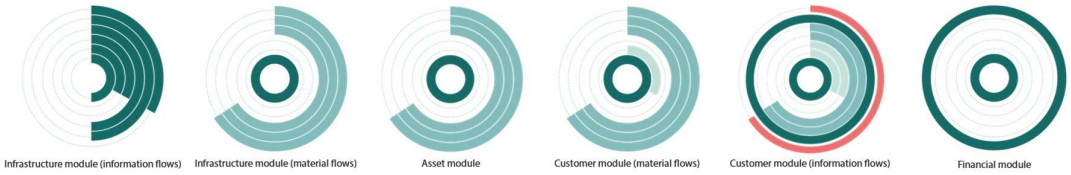

Figure 49. Summary of Noorderliefde project CE results.

Figure 49 depicts the different processes in the Noorderliefde project, those with a high, medium and low circularity are shown in darkest, light and lightest colour respectively. Each ring represents a building layer, and the red ring shows the degree of CE promotion. In analysing the methods applied for the fully circular ring representing the *Stuff* layer and the CE methods needed to close the rings of the remaining layers, this chapter goes on to make recommendations through two business models applicable for housing associations when adapting and reusing their assets.

6.1. Business models for housing associations

6.1.1. Relocatable building layers

This business model suggests regulating an activity found in the Noorderliefde project; capturing value on discarded “fast” building layers across the housing association’s portfolio, or across interinstitutional private and public networks. For instance, a housing association’s real estate building layers could be allocated across government real estate or vice versa. This business model sees a relocation operator deploying unused building layers hosted by a structure, in turn hosted by a site, to another structure located at a different site.

To implement this model, building layer component databases need to be shared with executors, customers and institutions involved in the network. For each building layer, there is a relocation operator that has knowledge and capabilities for managing all the building layer components across the investor’s portfolio. Components that are underutilised or are at their end-of-life, can be disassembled and relocated, replacing other underutilised, worn out or missing layers in a determined structure across the portfolio. A lesson learned in the MOR project was that material can be lost when relocated, so this business model highlights the importance of designing for modularity, disassembly and transportation. This model also adds value through an additional product customisation level. It allows customers to choose or be assigned the most convenient building layers for them (Table 38).

Table 38. Lifecycle stages of building layers and key actors for the relocatable building layers business model. Adapted from Arup & EMF, 2020.

	Life cycle stage						
Building layers	Design	Transportation and construction	Operation	Deconstruction, transportation adaptive reuse.	Operation	Deconstruction, transportation adaptive reuse.	Operation
Skin	Housing Association's relocation operator		Tenant	Site & Structure 1	Tenant	Site & Structure 4	Site & Structure 6 Tenant
Space plan	Housing Association's relocation operator		Tenant	Site & Structure 5	Tenant	Site & Structure 7	Site & Structure 2 Tenant
Services	Housing Association's relocation operator		Tenant	Site & Structure 3	Tenant	Site & Structure 1	Site & Structure 8 Tenant
Stuff	Housing Association's relocation operator		Tenant	Site & Structure 2	Tenant	Site & Structure 5	Site & Structure 9 Tenant

The table below shows a twelve-step action plan to apply this business model. Using the CE methodologies and variables defined in the Decision Support Framework (DSF), this step-by-step plan helps to achieve circularity in a building's different layers. In this recommendation, Table 39 also suggests possible actors who should be responsible for each activity, although the organisational roles are not the topic of this research, and the actors described in the literature may vary.

Table 39. Suggested activities for implementing relocatable building layers business model using the DSF (own work).

No.	Required activities	Variables	CE method	Actors
Infrastructure module				
1	Assign relocation operator	CE project procurement management, CE project human resource & CE scope	CE PMBoK	Long -erm investor and executers
2	Identify end-of-life service providers		CE-PMBoK	Long-term investor and executers
3	Establish operating agreements with municipalities		CE-PMBoK	Long-term investor and executers
4	Storage requirements if needed		CE-PMBoK	Long term investor and executers
5	Develop maintenance plan	CE project long-term scope	CE-PMBoK	Customer, investor, policy makers and executers
6	**C**omponent database across portfolio	Project integration management and MCI	CE-PMBoK and material flow analysis (MFA)	Executers
7	Developed design for: modularity, disassembly and transportation	Design for narrowing loops	Design for X (DfX)	Executers
		Design for slowing loops		
		Design for closing loops		
Asset & customer modules				
8	Involve tenants and project managers in placemaking strategies	CE cooperation	Customisation	Long-term investor and customer
		Adaptable building layers		
		Relocatable building layers		
		Flexible spaces		
9	LCA to establish targets	Consecutive LCA	Lifecycle analysis (LCA)	Long-term investor and executers
10	Define destination of building layer at end of life	End-of-life provider		Service provider
Financial module				
11	Rent customised building layers to social sector	Product as a service	CE pricing method	Investor, customer, and government
12	Integrate lifecycle analysis and lifecycle cost **(**LCA and LCC**)** to set targets	LCC - LCA	LCC	Long-term investor and executers

6.1.2. Building layers as a service

Building layers as a service suggests that, rather than construction clients and tenants buying products from suppliers through sales contracts, they instead purchase service subscriptions. Thus, the service suppliers retain ownership of the building layers and are responsible for their maintenance, repair, or upgrading. The payment of the periodical subscription by the tenant or the housing association is linked to performance indicators during the operational life of the component. These payments include maintenance and repair costs.

As service providers are paid according to component performance, they have the incentive to monitor their components and also to offer long-lasting components, following CE methodologies.

This business model was implemented partially in the Noorderliefde to some parts of the stuff building layer through a circular kitchen provider, and could be applied to the other layers of the building and site. Like in the Noorderliefde case, the skin and the structure can be owned by the housing associations in the adaptive reuse process, and the CE responsibility can be transferred to other suppliers by CE rental or leasing contracts with the association or the tenants. Something that was lacking in the case study, which is important for a fully circular project, is the assignation of end-of-life providers responsible for recycling material owned by housing associations at the end of their lifespan.

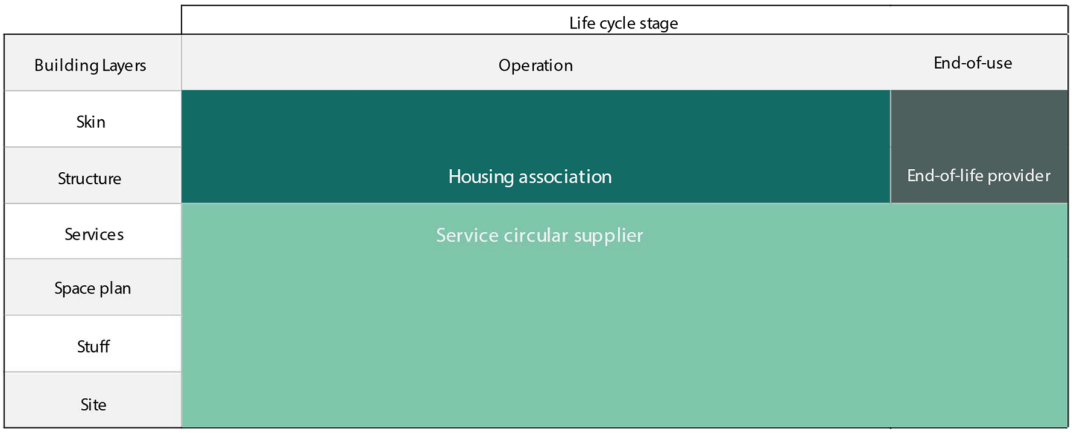

Figure 50. Lifecycle stages of building layers and key actors in the building layer as a service business model. Adapted from Arup & EMF, 2020.

The ten steps defined in Table 40 need to be followed to make the suggested building layers into a service model. These steps were defined with help of the DSF and can be implemented in practice to achieve a fully circular building by adapting and reusing the skin and structure owned by the housing associations. Table 40 includes suggested actors, but defining who should execute the methodologies is not the aim of this research, and these can vary within the organisational structure.

Table 40. Suggested activities for implementing product-as-a-service building layers business model using the DSF.

#	Required activities	Variable	CE method	Actors
Infrastructure module				
1	Develop CE agreements with service providers.	CE project procurement management, CE project human resource & CE scope	CE PMBoK	Long-term investor and executers
2	Identify end-of-life contractors for owned building layers		CE-PMBoK	Long-term investor and executers
3	Build consortia with service suppliers for building layers		CE-PMBoK	Long-term investor and executers
4	Establish operating agreements with service providers		CE-PMBoK	Customer, investor, and executers
5	Develop operation and maintenance strategies considering Material Flow Analysis	Implement Material Circularity Index	MFA	Executers
6	Developed design for: modularity, disassembly, and transportation	DF Narrowing loops DF Slowing loops DF Closing loops	Design for X (DfX)	Executers
Asset & customer modules				
7	Engage tenants and project managers in placemaking strategies	CE Cooperation Adaptable Building Layers Relocatable Building Layers Flexible Spaces	Customisation	Long-term investor and customer
8	LCA to establish targets	Consecutive LCA End-of-life provider	LCA	Long-term investor and executers
Financial module				
9	Rent customised building layers to social sector	Product as a service	CE Pricing Method	Investor, customer, and government
10	Integrate LCA and LCC to establish targets	LCC - LCA	LCC	Long-term investor and executers

A firm can implement these business models by using the framework outlined in this document as a support to define strategies in the value chain. The DSF guides the actors in choosing the necessary CE methodologies and variables that can be used in each building layer to achieve circularity.

6.2 Further research

As the results of this research are the output of a small sample, and due to limitations in the access to information, it could be of value to validate the DSF against other information sources and with new variables. The DSF can be used as a quick CE snapshot of the project processes. The model's output can be used to assess the degree of circularity in different areas of a constructed asset, or to make decisions that include CE principles in the project mission. The framework may be strengthened through testing and validation on other cases.

Exploring limitations and enabler for the application of CE methodologies like MCI and the LCA in practice is required, these methodologies are explored conceptually through the MOR project in this research. The practical impact of these methodologies therefore needs to be studied further.

The user's role in the CE economy could also be explored further. The idea of implementing product-as-service and involving the user as a tenant of the building layers are highly circular procedures, if the building layers are "clean" products. Research into ownership relations between the user the building layers is still scarce. Adding to this field of knowledge could encourage a diverse CE that offers customisable pricing methods.

The influence of the user's behaviour on the degree of CE of the building layers could also be explored further.

07

Conclusions & Lessons Learned

7.Conclusion & lessons learned

This research solves the following question: *How can CE principles be applied in the business model for the adaptive reuse of office buildings?* The answer to this question is implementing the DSF described in this research. It explores how can CE be implemented in the value chain approaching the problem from different perspectives and not only the financial aspects.

This study shows that adaptive reuse is a circular activity, as it delivers the slowing of material cycles. Nevertheless, this activity still contributes to the embodied emissions of a building if CE is not implemented throughout the lifecycle of all the building layers. To address this situation, this research develops a tool for the assessment or prescription of CE process structures directed towards the built environment and the adaptive reuse of vacant buildings executed by housing associations specifically but based on processes important for defining any type of constructed asset's project mission.

The Table 41. Summarises the CE modules and procedures that can be applied to the BM sub elements to ensure CE in each of the process required to define the project's mission. The table also shows in a scale of low, medium and high how important is the variable individually for CE in the constructed asset and what combinations of variables are needed to ensure a high degree of CE Building layers.

Table 41. Summary of modules, CE sub elements, CE methods and validated variables used in the DSF.

CE modules	CE BM sub-elements	CE methods	Variables	CE degree	Total_CE Degree
CE infrastructure module	CE agreements	CE-PMBoK	CE project long-term scope	High	High (6)
			CE project cost management	High	
			CE project procurement management	High	
			CE project integration management	High	
			CE project human resource	High	
			Financial management	High	
	CE tangible resources	MFA	Material circularity index. (MCI)	High	High
			Reusable+ material analysis	Medium	
	CE design	Design for x	Design for narrowing loops	Low	High
			Design for slowing loops	Low	
			Design for closing loops	Low	
CE Asset module	CE building layers	LCA	Consecutive LCA	Medium	High
			Recycling end-of-life	Low	
CE Customer module	CE marketing	CE promotion	CE social media	Medium	High
			CE publications	Medium	
			CE website media	Low	
			CE in-store communication	Low	
	CE housing sector		User as owner	Low	Low

		CE user characteristics	User as customer	Low	High
			Ownership as long-term investment	Medium	
			Circular stakeholder as owner	High	
	CE customer characteristics	CE customisation	CE cooperation	Medium-High	High
			Adaptable building layers	Medium	
			Relocatable building layers	Medium	
			Flexible building layers	Medium	
			Recyclable building layers	Low	
Financial module	CE expenditure	LCC	Lifecycle costing LCC - LCA	High	High
	CE revenue streams	Pricing methods	Product service systems (PSS) of "clean" products	High	High
			Buy- and take-back	High	
			Material commodities	Medium	Medium

The DSF can work to make decisions at any time of the projects life cycle as it is like a snapshot of how the business processes are configured and what is the remaining distance required to reduce to achieve a fully CE project. The DSF proved methods and procedures to tackle the lack of circularity. Nevertheless, the DSF can be useful by an actor that is fully involved in the project and can manage to manoeuvre the process.

Different lessons learned about CE principles in the adaptive reuse value chain were identified by looking at the way organisations achieve CE in practice. Housing associations can find solutions in their portfolio. Noorderliefde project reused and relocated elements from the "stuff" layer located in other asset saving material resources and reducing embodied emissions within their portfolio, producing financial benefits. This activity can be further standardised and implemented in other building layers to increase the CE degree. The creation of flexible and shared spaces was also highlighted in the research.

To achieve relocation, housing associations need to consider their assets as systems of modular interrelated layers that can be separated and disassembled. Organisations need to understand the interdependence and different lifecycles of the layers. In this way, as the CE expert pointed out in their interview, housing associations should be involved in helping to co-create the solution throughout the process.

Housing associations are long-term thinking institutions with financial advantages due to their social purpose and governmental relations. According to the CE expert, housing associations are institutions with room for management experimentation and with long-term thinking capabilities that allow them to facilitate processes that involve a building layer's multiple lifecycles.

When testing the Noorderliefde using the DSF, the study shows a case where no CE methodologies were applied in almost all the building layers owned by the long-term investor. Slow building layers achieved medium CE degree while in the fast ones CE was non-existent. The only "fast" building layer with a high degree of circularity was outsourced and owned by a third

party that implemented CE in their business model. The lack of standardised CE methodologies in the renovation processes seems to be a main cause of the low score in the CE degree. The DSF helps explore the importance of CE methodologies in achieving circularity and should be tested further in more in-practice cases.

In the Netherlands, the government is an important stakeholder as a landowner and with the steering capabilities of spatial planning. Housing associations and government partnerships based on CE agreements are an important enabler to achieve circularity in the urban fabric.

08

Reflection

8.Reflection

In this research, I took the adaptive reuse of office buildings as a starting point for exploring the real estate field. Adaptive reuse is explored in the Faculty of Architecture at TU Delft as a way to address social, economic, and environmental burdens in the built environment. In examining the viability of this activity helped me to develop a broader understanding of how our understanding of buildings can be limited by the idea that traditional procedures are immutable. Adaptive reuse made me think about origin and tradition in the built environment in a very conceptual way. I realised that new interpretations of traditional procedures can emerge, and – if carried out consistently – can build the traditions of the future.

This period of study was punctuated by news of environmental catastrophes, climate crisis, European measures to lower carbon and energy emissions, and a global pandemic which has brought much of human activity to a standstill. These factors focused my attention on how the built environment, from the real estate management perspective, could be moulded into a fully-sustained circular economy, thus becoming one of the building blocks of a better world for future generations.

At the nexus of adaptive reuse and the circular economy, I explore why it is that adaptive reuse does not deliver completely circular projects in practice. I also examine how the discursive uncertainty around what constitutes "fully circular" and what does not has limited the possibility of achieving that aim. This research brings together methodologies and procedures from different fields, and validates their practical application to circular adaptive reuse projects through two Dutch case studies. One case study is a brick and mortar example, and the other is a conceptual exercise between academics, students, and industry actors. The use of two case studies is intended to strengthen the decision support framework produced as an outcome of this research, in a way that a purely conceptual approach could not have achieved. Similarly, drawing on the business field, a project mission centred around constructed assets, and CE methodologies (found in the literature and validated in practice), helped to create a robust and integrated framework.

As mentioned above, the research process coincided with a global pandemic and resulting social distancing measures, which complicated the data collection phase. Social distancing replaced physical encounters, and restricted communications to email, social media applications, and video software. On the other hand, the changed situation may also have led participants to think and respond to this research in unusual ways.

8.1 Ethical issues and dilemmas

There were no ethical problems or dilemmas during the research. However, it is expected that, although the environmental burden will impact negatively on most of humanity, market-oriented organizations in the built environment may not be willing to collaborate in this type of research that fosters an economic transition. Organisations tend to operate using traditional, well-known, resource-based practices, and it appears that the primary resources needed to do so are not yet scarce enough to raise the alarm. In practice, the degree of rigour applied to the implementation of CE will depend on the political will to really collaborate in the sustainability of the built environment.

09

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Table of figures

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Appendix

10. Appendix.

10.1. Interview Protocol Form

Institutions: Delft University of Technology.

Interviewee: Organization representative

Interviewer: TU Delft MSc student Christian Lesmes.

Survey Section Used

_____A: Interviewee background

_____B: Circular business model

Other Topics Discussed:

_____

Documents Obtained:

_____

_____

Post Interview Comments or Leads:

_____

Introductory Protocol

To facilitate our notetaking, we would like to audiotape our conversations today. Only researchers on the project will have access to the tapes which will be eventually deleted after they are transcribed. Essentially, this document states that: (1) all information will be held confidential, (2) your participation is voluntary, and you may stop at any time if you feel uncomfortable, and (3) we do not intend to inflict any harm. Thank you for agreeing to participate. Please read and sign the following consent form if you agree to participate in this research interview.

We have planned this interview to last no longer than one hour. During this time, we have several questions that we would like to cover.

Introduction

I invited you for this interview because of your participation in the ___ project. I believe you have knowledge on the scope of the Circular Economy (CE) in the building industry, and especially in the circular elements implemented in the ___ project. The main aim of this research is to explore how CE principles can be implemented in the adaptive reuse of

vacant offices into housing business models and configure a framework that can be useful to make decisions on this matter.

This research does not have as an aim to evaluate your working techniques. It is directed to learn about the practices and experiences that can create opportunities for the implementation of CE in the built environment.

A. Interviewee Background

Interesting background information on interviewee:

1. Can you briefly describe what your role in the C____ project?

The following questions are related to the Business model of the ___project. The parts of this questions are based on the nine blocks from the Osterwalder Business model canvas presented in the following diagram:

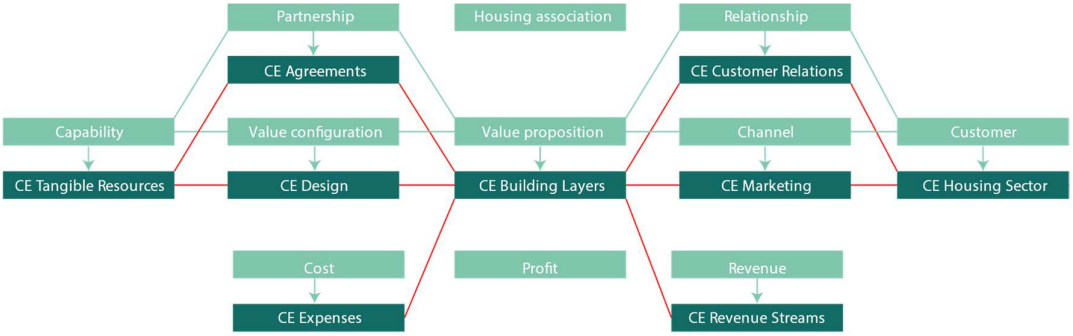
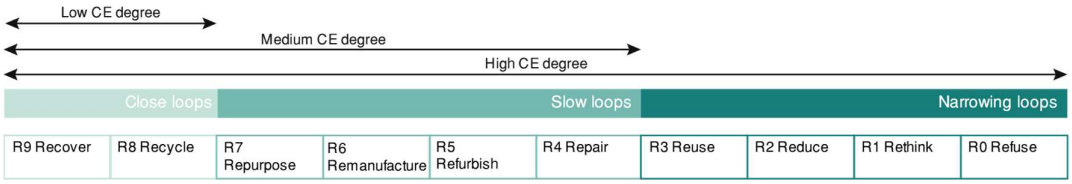


Figure 51. Overview of CE sub-elements in the BM canvas (Own work).

A high degree of circularity is understood as the capacity for the project to implement the 9Rs represented in the following image:



Achieving from, the R9-R8 is considered low, R9-R3 Medium, and R9-R0 a high circularity degree.

B. Circular Business Model

I. Partnerships/ CE agreements and information

1. Who do you think are the key actors in the ___ project and what were the roles they played for the achievement of circularity in the project?

2. What do you think are the most important features from the project management perspective for the achievement of the circular ___ project concerning the following topics?

a. Project management scope.
b. Project cost management.
c. Project Integration management (organisation structure).
d. Project financial management.
e. Project Human resources.

3. Which of the mentioned topics would you consider of high priority, medium or low priority for the achievement of circularity in the ___ project?

II. Capabilities / CE tangible material cycles

1.What do you think were the enablers or challenges to implementing Material Flow Analysis and or Material Circularity Index tools in the ___ project?

2. Apart from the mentioned tools, other mechanisms directed to evaluate and monitor the material flows, emissions or waste were implemented in the project?

3. Do you consider the mentioned mechanisms of high, medium, or low priority for the achievement of circularity in the ___ project?

III. Value configuration / CE design

1.Which of the following aspects were considered in the design processes?

Design for Assembly
Design for manufacture
Design for Durability
Design for Recyclability
Design for Remanufacturing
Design for Disassembly
Design for minimize material usage
Design for Mass customization
Design for energy Efficiency

2. Were there any other design strategy implemented in the ___ project?

3. What do you think are the main barriers and enablers to implement design strategies?

4. Which parts of the building should most preferably be considered when implementing the mentioned design strategies?

5. Which of the following design strategies do you consider of high, medium or low priority for the achievement of circularity in the ___ project?

IV. Value Proposition / Stuff, Space, Plan, Services and Skin.

1. What do you think were the enablers or barriers of implementing a life cycle analysis in the ___ project?

2. Which parts of the building were most preferably considered when implementing LCA in ___?

3. Do you consider LCA of high, medium, or low priority for the achievement of circularity in the ___ project?

V. Distribution Channel / CE Marketing communication

1. What channels were implemented for the promotion of the circular initiatives implemented in the ___ project?

2. What do you think are the benefits of promoting CE principles within the marketing strategy of a circular project?

VI. Target Customer/ Housing Sector

1. Who is the costumer in the ___ project?
2. In order to achieve a high circularity degree, do you think the user should be the customer, the user should be the owner?

Probe: If the User should be the owner which stakeholder should be the owner?

VII. Relationship Management / CE customisable

1. How are the users of the ___ project planned to be or were involved in implementing circular initiatives?

2.What were the barriers and enablers to implementing modular and mass customisable products?

3. What parts of the building were considered for modularity, cyclable and mass customisable strategies?

VIII. Cost Structures / CE Expenditures

1. What do you think were the enablers and barriers for the integration of the life cost analysis with the life cycle analysis in the ___ project?

IX. Revenue / CE pricing methods

1. What pricing mechanisms are implemented in ___ project?

For example:
a. Sale of products with take back or buyback programs
b. Leasing/Renting
c. Product as service
d. Sales of products

2. What are the barriers or enabler to implement the mentioned pricing mechanisms?

3. What of the following pricing mechanisms do you think is required to achieve a high degree of circularity?

4. How is the income division spread through the project coalition in the ___ project?

a. Division per company.
b. Division per small coalitions.
c. Spread over all the value chain.

5. What are the barriers or enabler to implement the mentioned income division?

6. What of the following income division do you think is convenient to enable a high circularity degree? Why?