THE TRANSITION TOWARDS CIRCULAR ECONOMY IN THE DUTCH BUILT ENVIRONMENT:

An exploratory research on the application of Product-Service Systems as Circular Business Models for the products, components, and materials in the building layers

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Title:" The Transition towards Circular Economy in the Dutch Built Environment: An exploratory research on the application of Product-Service Systems as Circular Business Models for the products, components, and materials in the building layers"

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PREFACE

This journey started in September 2017 when I arrived to Delft to follow the Master of Science program in Management of Technology at Delft University of Technology. During the past years I have gained invaluable experiences and knowledge which have allowed me to evolve both in a personal and professional level.

This research project constitutes the conclusion of my studies and it would be impossible without the contribution of my graduation committee. First, I would like to express my appreciation to my supervisor, Dr. Ir. Jaco Quist for the invaluable guidance and clarifying insights throughout this process. Moreover, I would like to sincerely thank Ir. Marcel Ludema and Dr. Robert Verburg for their definite feedback and support. What is more, this project wouldn't be possible without the interviewees and participants in my case survey. Thank you for sharing your viewpoints and valuable insights regarding circular economy and the built environment.

At this point, I would like to express my love and gratefulness to the people I met during these two life changing years and shared this priceless experience with. I thank you from my heart for the amazing memories and cheers to the future ones. Following, I would like to thank my friends from Greece who I am more than grateful for having in my life. You have stood next to me all these years and proved that distance doesn't matter. Last but surely not the least, this journey would be impossible without the support and encouragement of my family, who has always given me the freedom to pursue my passions and dreams, whether in Greece, the Netherlands or Japan.

Yours sincerely,
Foteini

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EXECUTIVE SUMMARY

The current industrial system is established on one fundamental characteristic: a linear model of resource consumption that follows a 'take-make-dispose' pattern. However, the emerging concept of Circular Economy (CE) is proposed to change the current production and consumption patterns that put a significant burden on our planet and its environmental capacity. In this context, scholars argue that the built environment is one of the key sectors that can benefit maximally from the development of CE. The Dutch government recognized this opportunity and in the publication of the Transition Agenda: Circular Economy in the Netherlands by 2050 acknowledged the construction industry as one of the five key economic sectors and value chains which will be the first to make the shift. In order to support the transition towards a circular built environment, experts from academia, policy, and business advocate that innovative Business Models (BMs) that allow new ownership relationships are required. Therefore the focus of this research is the examination of Product –Service Systems (PSSs) and their application as Circular Business Models (CBMs) in the Dutch built environment for the Products, Components, and Materials (PCMs) in the structure, skin, and services building layers. Thus, the main research question formulated to guide this research is:

"What is the current state of product-service systems as circular business models in the built environment and how can its application contribute to a circular built environment?"

For answering the research question a literature was conducted in order to examine the relevant concepts, along with expert interviews with the aim to explore the barriers, enablers and opportunities of the application of the PSS CBM. Finally, two case studies were conducted with the aim to analyze the business models of companies who are active in the built environment and have successfully applied the PSS CBM.

In the literature review of this study the concept of circular economy is thoroughly examined by looking into its definition, goals, and principles. Furthermore, the built environment and its constituting elements are studied while significant focus is paid on the Dutch built environment, where CE practices are not yet accepted. Moreover, circular business models and product service systems were in-detail investigated. The review showed that PSSs as CBMs slow resource loops through product life extension, and close resource loops through disassembly, recovery at the End of Life (EoL) and reuse. However, PSSs are neither inherently circular nor sustainable unless intentionally designed in accordance to CE principles. What is more, the application of PSSs as CBMs in the built environment was examined by looking into the associated barriers and enablers. For this reason, literature on the barriers and enablers concerning (i) CE thinking in the building sector and (ii) the implementation of PSSs as CBMs was studied. In total, 30 barriers and 33 enablers were identified related to the first aspect, whereas 25 barriers along with 13 enablers were recognized concerning the second aspect. Subsequently, six categories of barriers and enablers were formed, namely: knowledge & culture, policy& legislation, finance & economic, supply chain, design, technology. The comparison of the barriers identified showed that the lack of knowledge and supporting regulations, the fragmented supply chain, along with the high investment cost, the difficulty of designing for EoL, and the design complexity were indicated in both literature related to CE in

the built environment and PSSs as CBMs. As concerns the enablers the ones which were in common are related to the Internet of Things and its implementation for data collection. In addition, the opportunities offered from the application of PSSs as CBMs for both the client and the company were investigated. Finally, four business model frameworks were studied for the design of the case study framework.

From the expert interviews, it was highlighted that product-service systems as circular business models are mainly perceived valuable and interesting for suppliers of technological products or start-up companies. Additionally, the application of PSSs as CBMs was examined for the structure, skin, and services layers separately, and it was observed that experts consider it interesting for all three of them; however, as concerns the structure layer of the building it was considered valuable under conditions. In addition, the barriers and enablers regarding the application of PSSs as CBMs in each layer were investigated. The main barriers in all three layers were financial and economical. As concerns the enablers, the main ones for the structure and services layers were related to the design and engineering of the PCMs involved, whereas in the case of the skin layer experts considered as the main enablers solving the financial and legal issues. Overall, common barriers identified in all three layers are the lack of financing the business model due to its high risk because of the layers' long lifespan, and the Dutch property law. By investigating the enablers it can be observed that the common ones were related to design for easy maintenance, assembly and disassembly. In addition, the materials and products utilized in the layers are important and the analysis showed that the ones which are easily reusable, raw material with high value in the long term, and the ones which have technology embedded may be more suitable to be serviced. Moreover, for all three layers building management and information systems facilitate the application of the PSS as a CBM. Furthermore, defining the services which can be provided or combining a performance model was considered important. Finally, the examination of the opportunities showed that the most important one was the lack of the burden of ownership products, and for the company being responsible for the products, components, and materials.

The purpose of the case study survey was the investigation of how organizations have managed to establish the PSS as CBM and make a successful business case out of it. For this reason the business models of two companies were investigated, namely Mitsubishi Elevators Europe which offers elevators as a service, and Alkondor Hengelo which delivers façades as a service. The analysis illustrated that for the successful implementation of product-service systems as circular business model looking at all the different elements of the business model is necessary and changing them in accordance to PSS and CE characteristics is necessary. Interestingly, even though the companies' focus on different building layers the cross case analysis illustrated that the similarities of their business models are more than the differences. In addition, both companies are working on have established the product-service system as circular business model; however, they are still working on linear projects. This is finding is important since it shows that in order to go through the transition period companies in the built environment should take small steps and experiment with circular business parallel with business as usual.

The discussion focuses on analyzing and presenting the limitations regarding the literature review, the expert interviews, and the case study survey. To continue, the managerial and academic relevance of this thesis is discussed. Specifically, this research contributes scientifically by examining CE's principles in the

built environment, by investigating the application of PSSs as CBMs in the sector, as well as by proving the business case of circular business models through the through the business model analysis of two case companies which have successfully applied the PSS CBM. On a managerial level, this research provides valuable insights to companies interested in integrating CE thinking in their way of doing business in the built environment. Subsequently, in order to reach to a conclusion and provide an answer to the main research question the findings of the literature, the expert interviews and the case study are utilized. Specifically, it is concluded that the PSS CBM may contribute to a circular built environment by slowing resource loops through product life extension, and closing resource loops through disassembly, recovery at the end of life, and reuse. However, it must be noted that for it to become a mainstream business model in the building sector there are numerous barriers which still need to be overcome. Finally, recommendations are provided to policy makers, suppliers, as well as for future research

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ABBREVIATIONS

BIM	Building Information Modeling
BM	Business Model
BMC	Business Model Canvas
BMI	Business Model Innovation
BREEAM	Building Research Establishment Environmental Assessment Method
C&NRB	Commercial and Non-residential Building
CBM	Circular Business Model
CBMI	Circular Business Model Innovation
CE	Circular Economy
DGBC	Dutch Green Building Council
EMF	Ellen MacArthur Foundation
EoL	End of Life
EU	European Union
IoT	Internet of Things
PCMs	Products, Components, and Materials
PSS	Product – Service System
S&CE	Soil and Civil Engineering
SBMI	Sustainable Business Model Innovation

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The current industrial system is established on one fundamental characteristic: a linear model of resource consumption that follows a 'take-make-dispose' pattern. While significant efforts have been put on the improvement of resource efficiency, any system based on consumption rather than on the restorative use of resources leads to serious losses along the value chain. Thus the linear production model incurs unnecessary resource losses in several ways, such as waste in the production chain, End-of-Life (EoL) waste, and energy use (EMF, 2013). In this context, the concept of the Circular Economy (CE) is proposed to change current production and consumption patterns that put a significant burden on our planet and its environmental capacity (Leising et al., 2018). CE is "*a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling*" (Geissdoerfer et al., 2017).

As supported by a number of scholars, the built environment is one of the key sectors that can benefit maximally from the development of CE (Akanbi et al., 2018; Smol et al., 2015). The urgency of the industry's successful transition towards this economic model is supported by a number of global megatrends. Activities and products of the construction industry are accountable for the generation of the largest percentage of the total global waste (Akanbi et al., 2018), and in the EU one third of all waste is generated by the sector (Debacker et al., 2016). Moreover, the global building industry is the largest consumer of resources and raw materials, is responsible for a dominant share of global greenhouse gas emissions in relation to electricity and heat production for buildings, as well as to manufacturing and construction processes (Pomponi & Moncaster, 2017; WEF, 2016; Debacker et al., 2016). In addition, a large proportion of all materials ever extracted are stored in the built environment (Sanchez & Haas, 2018). Furthermore, information technologies, such as Building Information Modeling (BIM), IoT, and e-commerce platforms, have seen a large jump in innovation in the previous years; thus enabling the creation of CE business approaches which were formerly impossible (Heinrich & Lang, 2019; Debacker et al., 2016). Moreover, in 2050 it is estimated that 9 billion people will be living on earth, which will lead to a global economy requiring about three times the resources currently used (Planing, 2018). Finally, by cause of the global economic crisis, soaring commodity prices and growing awareness of the human impact on the environment CE measures can be found in various environmental and economic policies (Debacker et al., 2016).

In this context, the Dutch government has set the tone on a global scale with the publication of the Transition Agenda: Circular Economy in the Netherlands by 2050 with the aim to create a future-proof sustainable economy (MIE & MEA, 2016). The Cabinet has chosen five key economic sectors and value chains, and one of them is the construction sector (MIE & MEA, 2016; Schult et al., 2015). According to the Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs (2016), the main reasons the transition towards CE in the built environment is that in the Netherlands more than 50% of all the materials used in the country are used in the built environment sector, the industry is responsible for 40% of total energy, 30% of total water consumption, 36% of total CO_2 emissions, and 35% of total waste production, according to the reference year of 2013 (MIE & MEA, 2016).

The urgency to shift towards a circular built environment lead the Dutch government to the following vision (MIE & MEA, 2016): "*By 2050, the construction industry will be organized in such a way, with respect to the design, development, operation, management, and disassembly of buildings, as to ensure the sustainable construction, use, reuse, maintenance, and dismantling of these objects. Sustainable materials will be used in the construction process, and designs will be geared to the dynamic wishes of the users. The aim is for the built-up environment to be energy-neutral by 2050, in keeping with the European agreements. Buildings will utilize eco-system services wherever possible (natural capital, such as the water storage capacity of the sub-soil).*"

The Dutch government and a number of scholars from businesses and academia support that the transition towards a circular built environment requires innovative Business Models (BMs) and new ownership relationships (Rios & Grau, 2019; Hart et al., 2019; Nelissen et al., 2018; Leising et al., 2018; Adams et al., 2017). Circular Business Models are a response to the inefficient management of resources in the traditional built environment (Michelini et al., 2017), and aim to generate profits from the flow of Products, Components and Materials (PCMs) over time (Bocken et al., 2016). Moreover, researchers advocate that the application of Product-Service Systems as CBMs can facilitate the implementation of the CE model in the built environment (Rios & Grau, 2019; Leising et al., 2018; Peters et al., 2017). This is mainly because the implementation of PSSs as CBMs in this sector enables new ownership structures, since suppliers retain the ownership of building PCMs, and the focus shifts from selling products to the delivery of services (Rios & Grau, 2019). However, the fact that there is still great uncertainty regarding the application of CBMs in the Dutch built environment, as well as the fact that the transition from traditional product-oriented business models to service-oriented ones is highly complex and contextual illustrates that further research is required (Hart et al., 2019; Rios & Grau, 2019; Adams et al., 2017; Yang et al., 2018).

1.2 PROBLEM DEFINITION

The modern built environment is still designed and operated in accordance to the principles of the linear economy in a "take-make-dispose" manner; thus putting significant pressure on the natural environment (Acharya et al., 2018; Pomponi & Moncaster, 2017). In this context, a number of scholars advocate the importance of the sector's transition towards circular economy (Rios & Grau, 2019; Hart et al., 2019; Nelissen et al., 2018; Azcarate et al., 2018;Adams et al., 2017). However, the shift towards this new economic model requires systematic innovation, which will allow the reintegration of resources recovered at the EoL in both sufficient quantity and high quality (Nussholz & Milios, 2017). For this reason, the design of built objects needs to be aligned with circularity principles at an early stage; thus enabling the recovery and reintegration of products at the EoL (Nussholz & Milios, 2017). In this respect, circular business models are considered as enablers to facilitate such an innovation (Rios & Grau, 2019; Hart et al., 2019; Nussholz & Milios, 2017; Debacker et al., 2016).

The circular built environment requires a different ownership model, since circular economy is based on the use of products, components and materials rather than their consumption (Rios & Grau, 2019;

Azcarate et al., 2018; Leising et al., 2018; Nussholz & Milios, 2017).This new ownership model is based on product-service systems, which allows a company to retain the ownership of buildings element and shifts their focus from selling products to the provision of a bundle of products and services; thus, the client purchases access, use, and performance (de Pádua Pieroni et al., 2018). Therefore, the application of product-service systems as circular business models is suggested for businesses active in the built environment that wish to innovate their business model in accordance to circular economy thinking (Rios & Grau, 2019; Azcarate et al., 2018; Leising et al., 2018; Nussholz & Milios, 2017; Peters et al., 2017).

The adoption of circular business models requires organizations' in the built environment to change the elements of their traditional business model; thus, business model innovation presents a way to apply circular strategies into a company's way of doing business (Nussholz & Milios, 2017). However, business model innovation for circularity lacks understanding and is still fragmented (Guldmann & Huulgaard, 2020; Pieroni, McAloone & Pigosso, 2019). A concerns product-service systems and their application as circular business models further investigation is required, since product – service systems are not inherently circular (Pieroni et al., 2019; de Pádua Pieroni et al., 2018; Michelini et al., 2017; Tukker & Tischner, 2006) and the transit from traditional product-based to service is complex and contextual (Yang et al., 2018).

The application of product-service systems as circular business models has been suggested by scholars for the products, components and materials of buildings (Rios & Grau, 2019; Fischer, 2019; Azcarate et al., 2018; Thelen et al., 2018; Carra & Magdani, 2016). Buildings are the most complex element within the built environment (Ngwepe & Aigbavboa, 2015). In this context, a number of scholars suggest looking at a building as a collection of layers that can be divided into products, components and materials creates a new perspective (Fischer, 2019; Thelen et al., 2018; Zimmann et al., 2016; Debacker et al., 2016). This is based on Stewart Brand "6S" framework (Fig. 1.1) which was introduced in 1995 and suggests that buildings consist of distinctive and interlinking layers, each with a different function and lifespan (Brand, 1995). The application of PSSs as CBMs has been successful for short and medium lived products, such as the ones in the Stuff and Space Plan (Carra & Magdani, 2016). However, scholars advocate that further investigation is required for its implementation for products, components and materials in the different levels of the building, such as the Structure, Skin and Services layers (Thelen et al., 2018; Carra & Magdani, 2016).

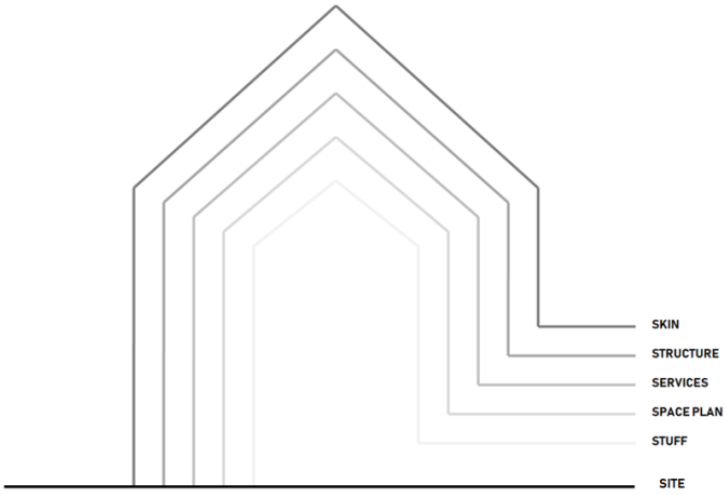

Figure 1. 1 Stewart Brand "6S" framework
Source: (Brand, 1995)

Even though circular business models in general and the product-service system ones in particular have been suggested as enablers for the shift towards a circular built environment, one of the main challenges recognized is the lack of convincing case studies (Hart et al., 2019). Therefore, there is a need to present clear and successful case studies which illustrate the viability of product-service systems as circular business models, as supported by academic researchers, companies' reports, as well as policymakers and regulators (Rios & Grau, 2019; Hart et al., 2019; Leising et al., 2018; Acharya et al., 2018; Thelen et al., 2018; Carra & Magdani, 2017; Peters et al., 2017; Zimmann et al., 2016; Nelissen et al., 2018).

1.3 KNOWLEDGE GAP & PROBLEM STATEMENT

Scholars from academia, business and policy suggest that product-service systems as circular business models can be applied for the products, components and materials in buildings' layers in order to facilitate the shift towards the circular built environment. However, the following knowledge gaps were identified in literature:

- Product-service systems have been successfully applied for products, components and materials in the Stuff and Space Plan layers of the building; however, further research is required for its implementation for the Structure, Skin, and Services layer.
- Case studies which demonstrate the viability of the implementation of product-service systems as circular business models in the built environment.

This thesis problem statement is as follows:
The built environment still operates in accordance to the linear economy in a "take-make-dispose" manner. A number of trends support the need of the sector's shift towards circular economy. Innovative business models which enable a new ownership model are considered facilitators to make the transition. Product-service systems have been successfully applied for products, components and materials in the

Stuff and Space Plan layers of the building; however, further research is required for its implementation for the Structure, Skin, and Services layer.

1.4 RESEARCH OBJECTIVES & RESEARCH DELIVERABLES

The objective of this research is to examine the application of product-service systems as circular business models for the products, components and materials in buildings' layers in order to contribute to the Dutch built environment's shift towards circular economy. In this respect, the main deliverable of this research will be an exploratory research on the opportunities, drivers, and barriers of the implementation of product as a service as a circular business model, along with the suppliers perception and the power and interest of the different stakeholders groups regarding it. What is more, the business models of two companies are analyzed in order to indicate the feasibility and profitability of the PSSs as CBMs in the built environment. Finally, practical recommendations for different stakeholder groups are provided in order to facilitate the adoption of product-service systems as circular business models in the Dutch built environment.

1.5 RESEARCH QUESTIONS

As a result of the definition of the scope of this thesis the main Research Question (RQ) which will be addressed is:

"What is the current state of product-service systems as circular business models in the built environment and how can its application contribute to a circular built environment?"

In order to guide the process of answering the main research question the following sub-research questions (SRQ) have been developed. The SRQs are presented and their main objective is discussed in the following section:

- **SRQ1:** What is the scientific progress on the circular built environment and circular business models and which are the main barriers and enablers?

This sub-research questions aims to provide knowledge regarding the current state of the circular built environment and circular business models, specifically product-service systems, according to literature.

- **SRQ2:** What are the opportunities, barriers and enablers regarding the application of product-service systems as circular business models in the Dutch built environment?

The objective of this sub-research question is to examine the opportunities, barriers, and enablers of the application of product-service systems as circular business models for products, components, and materials in the building layers. By investigating the opportunities it aims to illustrate the benefits of moving towards a new ownership model; thus it offers the potential to motivate businesses and consumers to move towards CE thinking. Moreover, the recognition of specific barriers hindering the uptake of the PSSs as CBMs for the Structure, Skin, and Services layers, as well as general reasons

hampering the application of this innovative business model works as a basis for the identification of the necessary steps to overcome them. The answer of this question is based on interviews with experts from the Dutch built environment.

- **SRQ3:** How have suppliers in the Netherlands successfully established product-service systems as circular business models for products, components, and materials in the building layers?

The objective is the analysis of the business model of companies which have successfully applied the product-service systems as circular business models in the Dutch built environment. It aims to illustrate how organizations have managed to incorporate both CE thinking and servitization principles in their business models and make a successful business case out of it. The answer of this question is based on cases study surveys.

1.6 RESEARCH METHODOLOGY & REPORT STRUCTURE

In the following Figure 1.2, the research design of this thesis project is displayed. The context of each chapter is presented by distinguishing six different stages, and a short reference to the methodologies utilized for the purpose of this thesis is done.

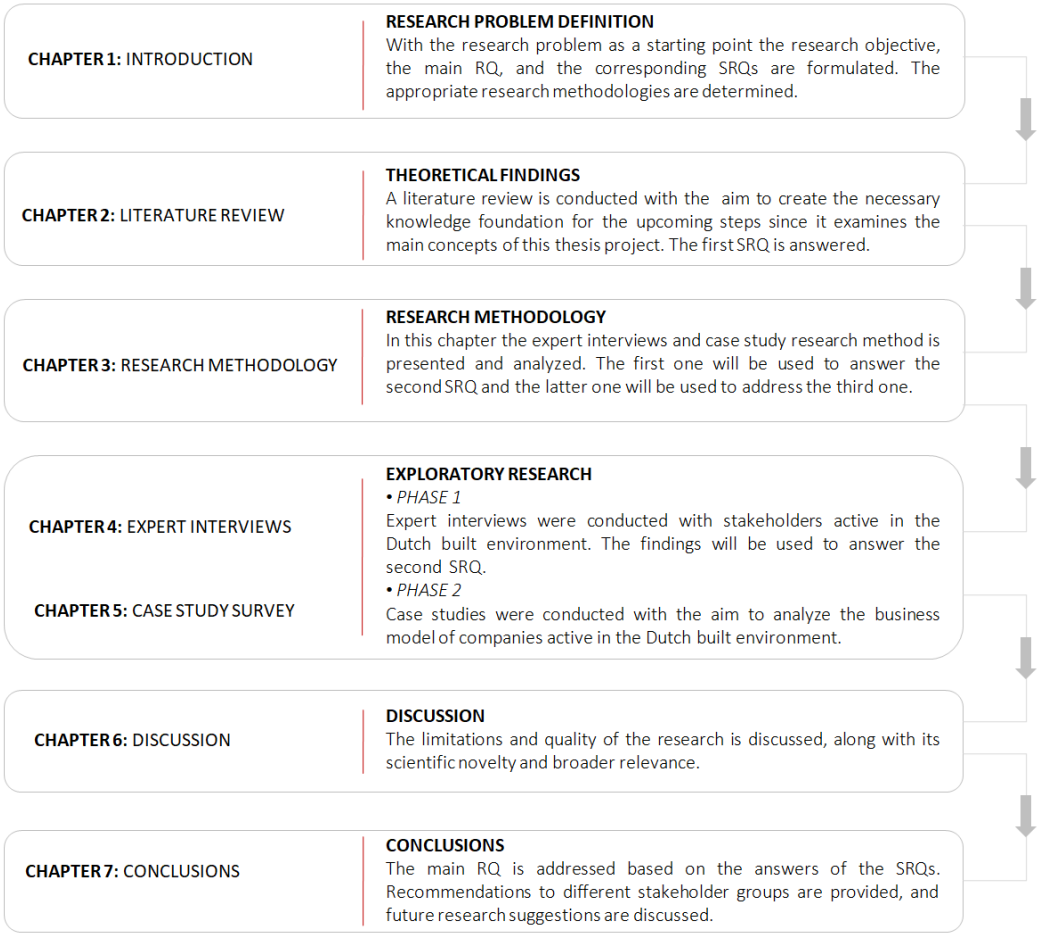

Figure 1. 2 Research Design of thesis project

1.7 RELEVANCE: SOCIETAL, SCIENTIFIC & MoT

1.7.1 SOCIETAL RELEVANCE

As has been highlighted, the application of CE thinking in the built environment is of high importance due to the sector's effect on the economy, the environment, as well as society as a whole. Therefore, the careful examination of how the PSS CBM can be applied in the Dutch built environment provides insight for companies on how to leverage circularity along with servitization principles to improve their business in line with the current need to move towards CE in the sector. Besides, CE is regarded as a top priority on both the national (Dutch Government) and international agenda (European Union). As a result, this research may provide insights which may prove to be valuable regarding changing policies, legislation and regulations in the shift towards a circular built environment. However, the most significant contribution that this research highlights the importance and contributes to circular thinking for ensuring that future generation will have access to the same resources and property as the previous ones.

1.7.2 SCIENTIFIC RELEVANCE

As concerns the built environment, scholars advocate that the application of the CE concept in the built environment sector is still in its infancy (Adams et al., 2017). Moreover, the identified need to explore innovative business models and new ownership structures has been supported as a potential way to work towards a circular built environment (Cruz Rios & Grau, 2019; Azcarate et al., 2018; Leising et al., 2018; Nussholz & Milios, 2017). This research explores the concept of CE in the built environment, by closely examining CBMs and PSS, and how their combination can facilitate the transition towards a circular built environment. The literature available on these topics as proven by the previous analysis is currently limited and needs to be further studied. In this respect, the findings and conclusions of this research may present interesting findings to expand the knowledge in these areas.

1.7.3 RELEVANCE TO MoT

For the master program of Management of Technology (MoT) three indicators have been established as suitable for a thesis project. These criteria were defined as follows:

- **CRITERION 1:** The work reports on a scientific study in a technological context

This research follows a scientific direction by analyzing CE and the application of innovative business models which allow new ownership models for the shift towards a circular built environment. In particular, the research takes a closer look on CBMs along with PSS and their application in general as well as in the sector specifically. In this context, their definitions and principles are presented and thoroughly analyzed based on scientific literature. In addition, scholars support that the successful transition towards CE requires rapid innovation in digital and information. This is especially true for the built environment, since as pointed out by Heinrich & Lang (2019), through the increase of complexity and high number of PCMs in a building, digitization, process automation and implementation of data standards need to be prerequisite. Therefore, in this research enabling technologies, will be studied and their role for facilitating material circularity in the building industry will be identified.

- **CRITERION 2:** The work shows an understanding of technology as a corporate resource or is done from a corporate perspective

Circular Economy is a model which aims to change the current state of the economy. As concerns the building industry is shifting towards CE companies active in the sector will be required to apply CE principles in their business model. This research will show that for the successful industry transition technological expertise is required and has to be incorporated in the business models. The involvement of innovative technology is necessary to support the shift of the built environment in this changing industry.

- **CRITERION 3:** Students use scientific methods and techniques to analyze a problem as put forward in the Management of Technology curriculum

Courses from the Management of Technology program that were used for information and methods in this thesis are: MOT2312-Research Methods, MOT1435-Technology, Strategy & Entrepreneurship, MOT1451-Inter- and Intra-Organizational Decision-Making, MOT1533-High-Tech Marketing, and MOT1531-Business Process Management and Technology.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter begins with an investigation of the thesis building block, namely the concept of circular economy and examines its definition, goals, and principles. Following this, the built environment sector is presented and its constituting elements are analyzed. Since the main focus of the thesis in on the Netherlands, the Dutch construction industry and the developments of the sector regarding CE are addressed. Subsequently, the different stakeholder groups are identified, and their roles in the linear built environment are discussed. Furthermore, the importance of looking at buildings as a collection of interlinking layers for the application of CE is investigated and presented through Brand's 6S framework. Next, the lifecycle stages of a building are examined, and how shifting towards CE in the built environment will change them is addressed.

In order to gain deep understanding of product-service systems as circular business models, the definition of business models is provided, their elements are analyzed, and their role for organizations is examined. Since the main focus of the thesis is on the application of innovative business models which adopt CE principles, circular business models are examined. However, in order for companies to implement CBMs in their business their traditional business models need to be transformed; therefore, the concept of circular business model innovation is investigated. Moreover, circular strategies are explained, and the different types of CBMs in literature are identified. One of the most promising ones for the shift towards CE, as supported by scholars is the product service system; thus, this business model is defined, and its main characteristics and principles are discussed. However, the PSS is not inherently circular; therefore, at this point how PSS can be aligned with CE principles is investigated. Moreover, the barriers, enablers and opportunities of the application of product-service systems as circular business models in the built environment are identified. Finally, business model frameworks which can be used for the case study survey are examined and the most suitable ones are chosen.

2.2 THE CIRCULAR ECONOMY

2.2.1 INTRODUCTION TO CIRCULAR ECONOMY

The established industrial system is founded on one primary characteristic: a linear model of resource consumption that follows a 'take-make-dispose' pattern. As a result, unneeded resource losses are produced, such as waste generation throughout the value chain and at the EoL (EMF, 2013). Researchers point out that if current business operations continue unchanged a population overshoot is unavoidable. In order to prevent this, it is important to break the current bond between economic development and material consumption (Fig. 2.1).

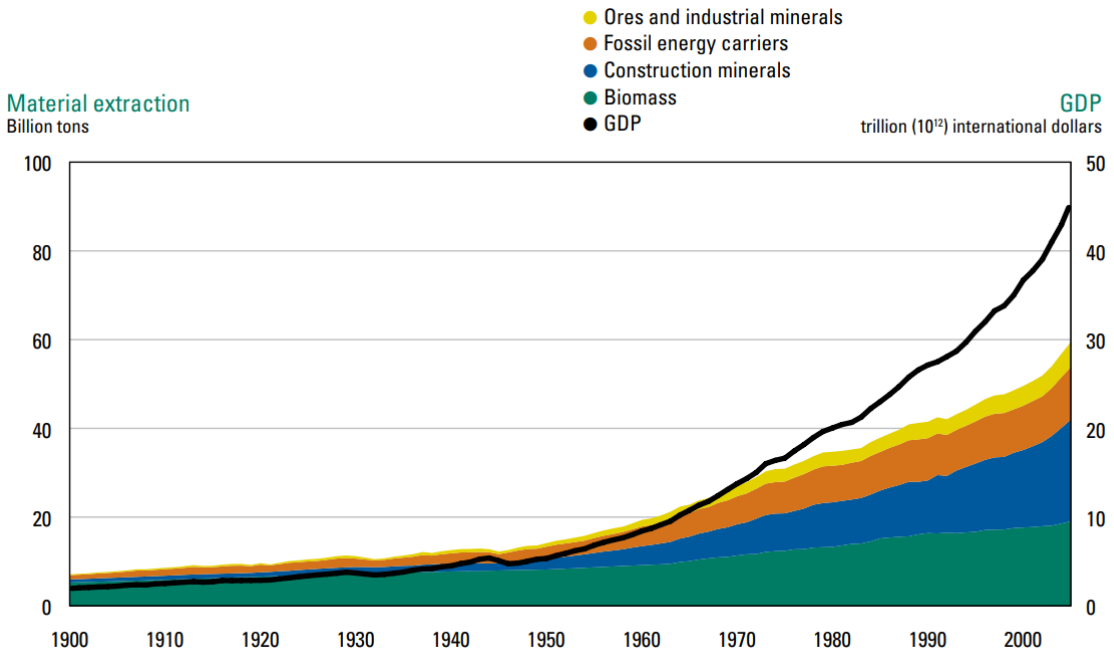

Figure 2. 1 Economic growth and resource consumption
Source: (Krausman et al., 2009)

Decoupling economic growth from finite resource consumption can be achieved by shifting from a linear to a circular economic model (Fig 2.2) (Kok et al., 2013; Thelen et al., 2018). This is because, in CE economic growth will be de-coupled from resource extraction due to closed loops of technical components and increase of sustainable renewable materials; thus reducing the impact on the climate (Carra & Magdani, 2016; Thelen et al., 2018).

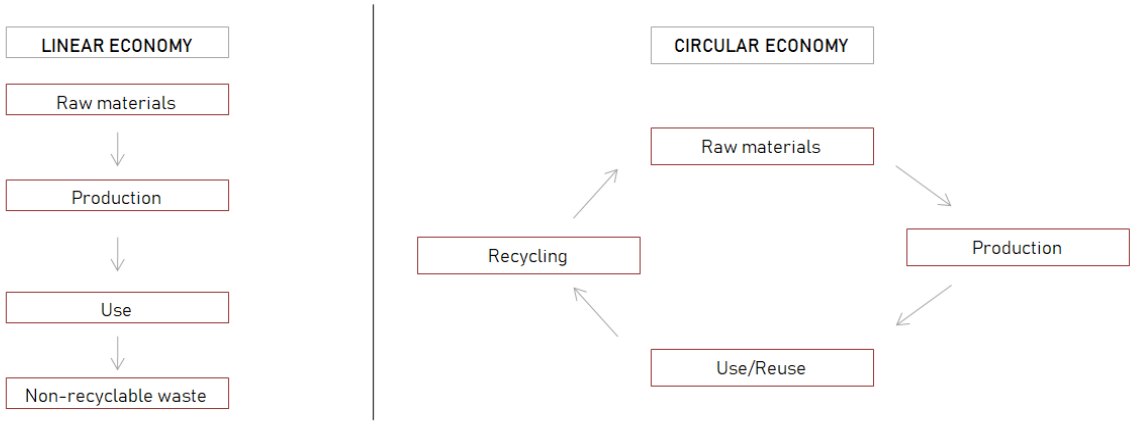

Figure 2. 2 The linear Economy and the circular Economy
Source: (Government NL, 2019)

2.2.2 THE HISTORY OF CIRCULAR ECONOMY

The roots of the CE concept are not asigned to one specific author (Lieder & Rashid, 2016; Winans, Kendall & Deng, 2017; Millar, McLaughlin, & Börger, 2019). According to Sarkis & Zhu (2018), its existence can be traced back in the 1800s, at the beginning of industrialization. However, the environmental economist Boulding (1966) has been commonly accepted as the one from whom the general idea emerged. Specifically, he proposed that the Earth was a closed loop system with "*limits assimilative capacity and as such the economy and environment must coexist in equilibrium*" (Ghisellini et al., 2017; Millar, McLaughlin, & Börger, 2019). As concerns the introduction of the term "Circular Economy" a number of scholars attribute its introduction to the environmental economists Pearce and Turner (1989), who built a theoretical framework based on the first and second law of thermodynamics in order to explain the shift from the traditional linear economic system to the circular economic system (Anderson, 2007; Ghisellini, Cialani, & Ulgiati., 2016; Su, Heshmati, Geng, & Yu, 2013; Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

The current understanding of the Circular Economy and its applications to industrial operations and economic systems has advanced to combine different contributions and characteristics from a variety of theoretical influences (EMF, 2015; Ghisellini et al.,2016; Winans et al., 2017; Geissdoerferet al., 2017; Korhonen, Birkie, Nuur, & Feldmann, 2018; Wautelet, 2018; Millar, McLaughlin, & Börger, 2019). According to EMF (2015), CE is related to different schools of thought which emerged in the 1970s but gained reputation and importance in the 1990s. The identified ones are presented and shortly analyzed in APPENDIX A (EMF, 2015; Ghisellini et al.,2016; Winans et al., 2017; Geissdoerferet al., 2017; Korhonen, Birkie, Nuur, & Feldmann, 2018; Wautelet, 2018).

2.2.3 DEFINITION OF CIRCULAR ECONOMY

A number of scholars mention that there are various ways of defining CE, whereas others point out that there is no commonly accepted definition of CE (Yuan, Bi, & Moriguichi, 2006; Lieder & Rashid, 2016; Kircherr et al., 2017; Millar, McLaughlin, & Börger, 2019). This may be explained by the fact that defining CE is a subjective matter, since different definitions come from how different people perceive and understand its notion (Kirchherr et al., 2017; Gladek, 2017). An interesting example to showcase this fact is by illustrating the differences between China's and the European Union's (EU) perspective on CE (McDowall et al., 2017). Specifically, the Chinese perspective on the CE is broad, and framed as a response to the environmental challenges which are the result of the country's both fast growth and industrialization, whereas the EU's conception of CE is narrower, since it mainly focuses on waste generation and business opportunities (McDowall et al., 2017).

Even though CE may lack a widely accepted definition, a common characteristic that most definitions share is the concept of cyclical closed-loop system (Leising, 2016; Damen, 2012; Yuan, Bi, & Moriguichi, 2006). On the other hand, what is supported to be the main difference is the reduction of material usage as described by the "R framework" (Yuan, Bi, & Moriguichi, 2006), meaning that a number of scholars

support that the framework should be part of the definition of CE, whereas others consider it as a strategy (Figure 2.3) (Leising, 2016).

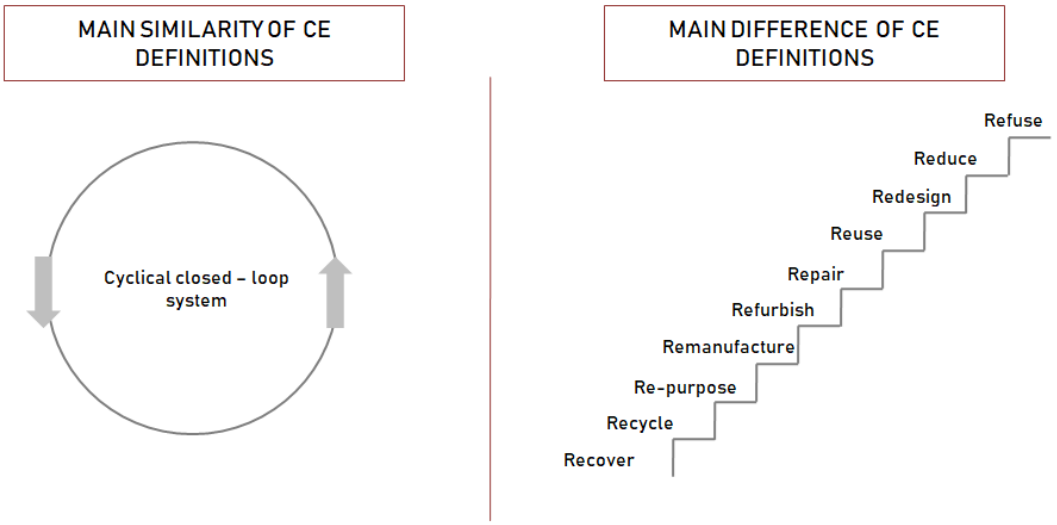

Figure 2. 3 The main similarity and the main difference of circular economy definitions
Source: (Damen, 2012; Yuan, Bi, & Moriguichi, 2006, Leising, 2016)

In spite of CE's academic roots, it has been suggested that the modern understanding of CE and its practices have been mainly promoted by businesses and policy-makers (Korhonen et al., 2018; Millar, McLaughlin, & Börger, 2019). Therefore, the most renowned definition has been framed by the Ellen MacArthur Foundation (EMF), a business development agency with the mission to accelerate the transition towards CE (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Millar, McLaughlin, & Börger, 2019). EMF (2013) introduces CE as: *"An economic and industrial system that is restorative and regenerative by design and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles."*

However, for the purpose of this thesis the definition which will be used is the one of Kirchherr et al. (2017). The reason is that this definition is a result of academic literature research on the subject, since the researchers examined 114 different definitions of CE. In addition, it is one of the few which references novel business models as an enabler for CE, which is the main focus of this study. According to Kirchherr et al. (2017): "*Circular Economy is an economic system that replaces the 'end of life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers*".

2.2.4 GOALS AND PRINCIPLES OF CIRCULAR ECONOMY

Most of the scholars agree that the goals of CE should have a contribution to all three dimensions of sustainable development, and not economic gain only (Geissdoerfer et al., 2017; Korhonen, Birkie, Nuur, & Feldmann, 2018; Thelen et al., 2019; Schroeder, Anggraeni, & Weber, 2019; Kristensen & Remmen, 2019). This fact is also illustrated by the working definition of CE by Korhonen, Birkie, Nuur, & Feldmann (2018).Therefore, the goals of CE can be broken down using the three dimensions of sustainable development: economic, social and environmental. Economically, the main goal of CE is to increase the economic performance of the system, by increasing both the sustainable performance of locations and companies, and by decoupling economic growth from scarce resource consumption (Velte, Scheller, & Steinhilper, 2018). Environmentally, the main objective of CE is to increase the ecologic performance of the system (Velte, Scheller, & Steinhilper, 2018). This can be accomplished by increasing environmental friendliness, decreasing negative impacts on the environment, and by increasing regeneration of products, elements and material (Velte, Scheller, & Steinhilper, 2018). Finally, social aim of CE is to increase human welfare, by increasing the number of jobs, by improving social standard and increase social fairness (Velte, Scheller, & Steinhilper, 2018). In APPENDIX B the hierarchy of CE objectives as presented in the work of Velte, Scheller, & Steinhilper (2018) is highlighted by breaking them down in accordance to the three pillars of sustainability.

In this context, it is important to note that the most promoted aspect out of all three is the economic one (Yuan, Bi, & Moriguichi, 2006; Geissdoerferet al., 2017). At the same time, Geissdoerferet al. (2017) and Korhonen et al. (2018) argue that a number of authors seem to leave out the social dimension of CE, thus this dimension remains relatively underexplored.

According to Niero & Rivera (2018), there is no exhaustive list of CE principles; however, the most promoted ones are the three principles created by the EMF (2015), namely:

- **PR1:** Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows

The basis of this principle is dematerialization of utility. This is achieved when the choice of resources is carefully made and the processes and technologies use renewable sources. As concerns the enhancement and preservation of natural capital with the creation of nutrient flow within the systems and with the regeneration of valuable resources.

- **PR2:** Optimize resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles

This principle illustrates the product and component design should enable remanufacturing and refurbishment with the aim to keep technical components within closed loops.

- **PR3:** Foster system effectiveness by revealing and designing out negative externalities

This principle highlights the importance of damage reduction in systems and areas, such as mobility, shelter and education, as well as the significance of adverse externalities management of adverse externalities, like water, noise pollution and air.

To understand the closed loop concept, as well as the main principles CE the EMF created the butterfly diagram. This model seen in Figure 2.4 consists of multiple cycles: the right is the technical and the left is the biological one. Within the biological cycle, renewable and plant-based resources are used, regenerated and safely returned to the biosphere. Within the technical cycle lie the man-made products. Two important aspects of the CE are depicted in this side of the, namely: the role of the consumer changes since he becomes the user, shifting from ownership to usership, and the inner circles are more desirable, since they require less energy and processing. This, for instance, means that maintenance of a product is more preferable than refurbishment.

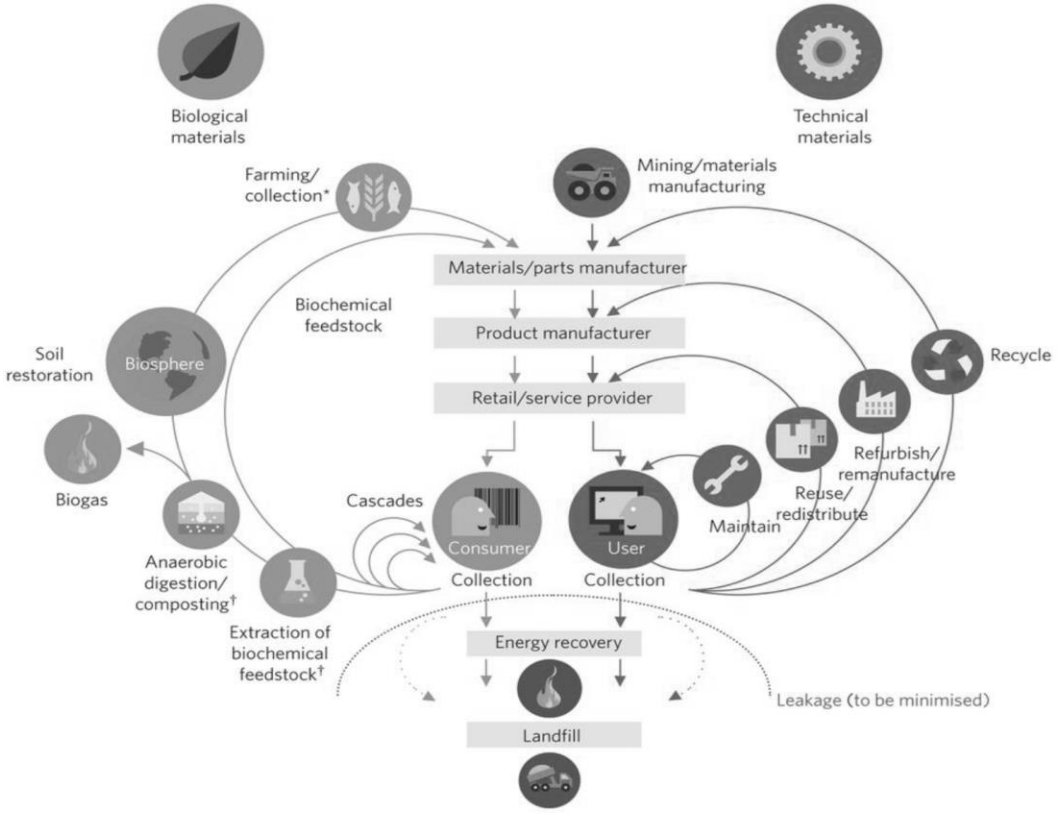

Figure 2. 4 The butterfly diagram of circular economy
Source: (EMF.2013)

2.3 THE BUILT ENVIRONMENT

2.3.1 DEFINITION & COMPONENTS OF THE BUILT ENVIRONMENT

The introduction of the built environment as a concept was relatively recently introduced by social scientists (Hassler & Kohler, 2014). A broad definition of the built environment is provided by Roof & Oleru (2008) who described it as: "*the human-made space in which people live, work, and recreate on a day-to-day basis. It includes the buildings and spaces humans create or modify*". More comprehensively,

Bartuska (2007) formulated a definition based on four interrelated characteristics, according to which "*the built environment is:*

1. *Everything humanly made, arranged, or maintained*
2. *Intended to serve human needs, wants, and values*
3. *Created to help us deal with and protect us from the overall environment*
4. *All of its individual elements affect both the built and natural environment, as well as human-environment relationships".*

The definition of Bartuska (2007) will be used in this research since it illustrates that all of the built environment's elements have an effect both on nature and human-environment relationships. This is a very important aspect since the CE model in the built environment is promoted for the mitigation of human activities on nature and humans.

Following the work of Bartuska (2007), the researcher mentions that the built environment consists of seven interlinked components, the sums of which define its scope (Table 2.1).

Table 2. 1 The components of the built environment
Source: (Bartuska, 2007)

COMPONENT	EXPLANATION
PRODUCTS	• Materials and commodities created for the extension of human capacity for the performance of specific tasks.
INTERIORS	• The arranged grouping of products commonly enclosed within a structure. Their creation aims to facilitate of activities and the mediation of external factors.
STRUCTURES	• Planned groupings of spaces defined by and constructed of products.
LANDSCAPES	• The exterior settings or areas for planned groupings of spaces and structures. They are a combination of the natural and built environments.
CITIES	• Groupings of structures and landscapes characterized by a variation of both sizes and complexities.
REGIONS	• The combination of cities and landscapes of various sizes and complexities. They are often clustered for the definition of common political, social, economic, and/or environmental characteristics.
EARTH	• The Earth includes all of the above.

This study is undertaken with respect to structures, specifically buildings as highlighted in chapter 1. Buildings are structures which include interiors and products; the interiors include everything that is enclosed in the building varying from furniture, elevators, walls etc and the products include materials used in the construction of buildings, such as bricks and mortar, wood, concrete and steel, polymers and plastics. All of these elements exist in the different layers of the building. This is illustrated in Brand's "6S" shearing layers theory which is presented in chapter 1 and analyzed in detail in chapter 2.3.3.

2.3.2 THE DUTCH BUILT ENVIRONMENT

This thesis the focuses on the Dutch built environment, mainly because market developments, policies, and trends of the building sector significantly vary from country to country. The built environment is the result delivered by the building industry (Rios & Grau, 2019), thus the data provided concern the Dutch construction sector.

In 2007 the economic crisis strongly affected the Dutch construction sector (Schult, 2015). Specifically, the industry experienced an economic downturn as a result of the housing market crisis, which marked the sector from 2009 to 2014. The results of the crisis were felt throughout the country, since building projects were paused or called-off, a number of businesses went bankrupt varying from suppliers to building, and buildings in either commercial estates or business parks became vacant (Schult, 2015). However, a slow recovery took place from the late 2014 early 2015. From that point onwards, output in the Dutch construction industry has grown at a faster pace than the average across Europe, as shown in Figure 2.5 (CBS, 2016). The sector has increasing output every year since, and in 2018 construction saw the strongest production growth of all industries, as illustrated in Figure 2.6 (CBS, 2019). The industry, has recovered from the crisis, and the second quarter of 2019 the Dutch construction sector increased to 9489.46 EUR Million from 9178.06 EUR Million in the first quarter of 2019. GDP, reaching an all time high (Trading Economics, 2019). All this facts and figures illustrate the significant role of the building industry and its role it plays in the Dutch economy.

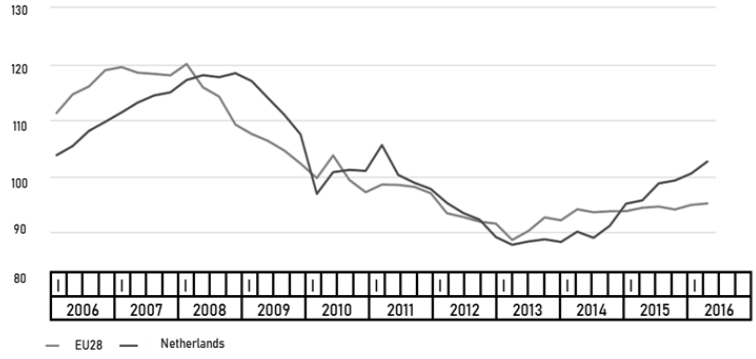

Figure 2. 5 Construction output in the Netherlands and in the EU
Source: (CBS, 2016)

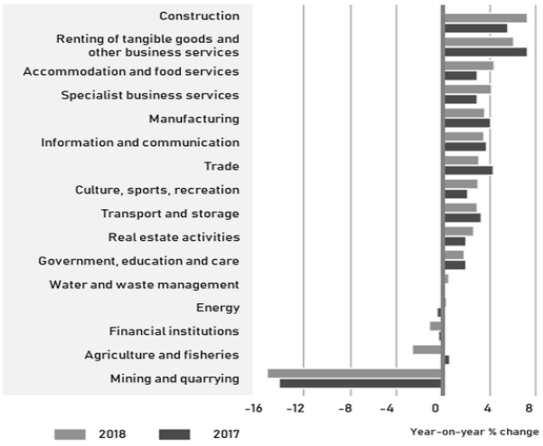

Figure 2. 6 Outputs in industries
Source: (CBS, 2019)

One of the positive aspects of the crisis was that a number of initiatives were formulated with the aim to boost the industry, and the concept of 'Circular Economy' is considered one of the most critical ones (Schult, 2015). At this point it is important to understand the meaning of CE for the Dutch built environment.

The Dutch building industry is subdivided into two main sectors (Schult, 2015):

- Commercial and Non-residential Building (C&NRB)

- Soil and Civil Engineering (S&CE)

The two significantly differ at core; the S&CE mainly involves public commissioning, and the stakeholder groups involved are smaller in number and more homogeneous. On the other hand, the C&NRB largely entails private funding and the actors involved are larger in number and more diverse in terms of business, since both small and larger players are active in it this category (Schult, 2015; MIE & MEA, 2016).

The issue which the application of CE aims to overcome is the high rate downcycling materials. In the country already 95% of the construction and demolition waste from the C&NRB sector is recycled, which means that the majority of the materials are not reused at the same or a higher level (Fig. 2.7) (Schult, 2015; MIE & MEA, 2016). Specifically, the construction rubble is processed and subsequently utilized as material for foundation in the S&CE sector. However, due to the increasing trend of the S&CE sector to use residual material from other sources, the need for such foundation material is expected to decrease. This is a stimulus for the C&NRB sector to move towards CE and upcycle resources instead of downcycle them (Schult, 2015; MIE & MEA, 2016).

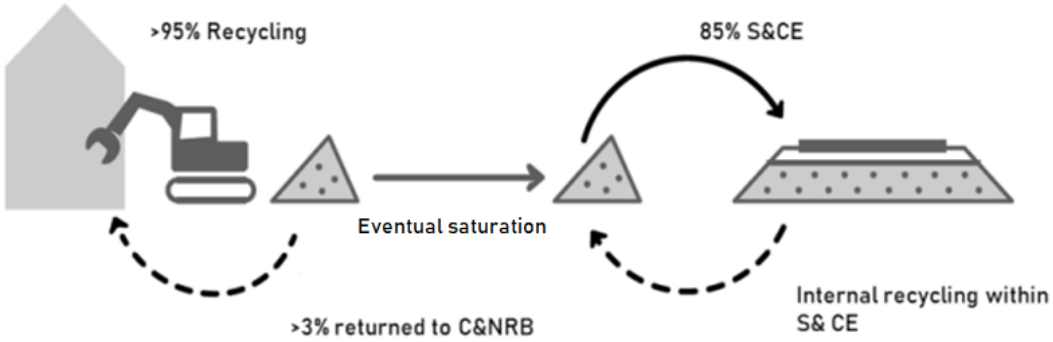

Figure 2. 7 Construction and demolition waste usage in the Dutch construction industry
Source: (Schult et al., 2015)

As concerns buildings, introducing CE's principles on all of its lifecycle stages can bring energy savings, CO_2 reduction (MIE & MEA, 2016). In addition, significant opportunities arise from raw materials and waste reduction. In addition, it can generate quality improvement and cost reduction throughout the object's life cycle (MIE & MEA, 2016).

Even though moving towards CE in the construction industry has to offer a number of benefits its practices are not yet accepted in the sector (MIE & MEA, 2016). However, a number of companies, varying from innovative start-ups to well-established multinationals, along with stakeholders, such as municipalities and architects have already started experimenting with CE principles, and some of the most important projects are (MIE & MEA, 2016):

- The Park20|20 in Hoofddorp
- The Overtoom urban garden project in Amsterdam
- The Knoop national office project in Utrecht
- The town hall of Brummen

At the same time, a number of Green Deals have been signed concerning CE in the built environment. This illustrates, that parties both from the public and the private sector are cooperating at the local level with the aim to close the materials cycle (MIE & MEA, 2016). In addition, the Circular Buildings Green Deal focuses on the formulation of a "buildings passport" outlining a building's circularity (MIE & MEA, 2016). Moreover, the Dutch Green Building Council (DGBC), which is the national social organization committed to make the built environment future proof, has been actively working towards CE in the sector. Specifically one of DGBC's roles is the development and management of the Building Research Establishment Environmental Assessment Method (BREEAM) mark in the Netherlands, which includes various quality marks as can be observed in Table 2.2

Table 2. 2 BREEAM – NL
Source: (BREEAM, 2019; Kubbinga et al., 2018)

BREEAM-NL CATEGORY	EXPLANATION
NEW CONSTRUCTION & RENOVATION	• Determines the sustainability performance of new buildings
IN-USE	• Used for the assessment of existing buildings on three levels, namely building, management and use
AREA	• Used for the assessment of the sustainability performance of area development
DEMOLITION & DISASSEMBLY	• Used for demolition projects.

For the acceleration towards the circular built environment DGBC collaborated with partners from the industry with the aim to formulate strategies and indicators for possible inclusion in BREEAM New Construction and Refurbishment & Fit-Out (BREEAM, 2019; Kubbinga et al., 2018).

2.3.3 MOVING TOWARDS THE CIRCULAR BUILT ENVIRONMENT

In order to move towards the circular built environment it is important to comprehend how the current linear built environment is operating. For this reason, the different stakeholder groups active in the sector are examined. Next, circular buildings are defined and the significance of looking at them as a collection of shearing layers is investigated based on Brand's "6S" framework. Finally, the lifecycle stages of the buildings in the linear built environment and how they should be approached in the circular one is analyzed in the following sections.

STAKEHOLDER GROUPS IN THE BUILT ENVIRONMENT

Stakeholders, as originally defined in theory are "*groups or individual who can affect or are affected by an issue*" (Schiller, Winters, Hanson & Ashe, 2013). Numerous stakeholders are active in the built environment and involved during the buildings' lifecycle stages. The stakeholders and their roles in the linear built environment are described in Table 2.3 Since they are the ones which will drive the shift towards a circular built environment, it important their function and interests.

Table 2. 3 Built environment's stakeholders and their roles
Source: (Hendrickson, Hendrickson, & Au, 1989; Peters et al., 2017; Thelen et al., 2018)

STAKEHOLDER GROUP	ACTOR	ROLE
OWNERS & PLANNERS	Developers	• They are involved in the construction, redevelopment or refurbishment. • They consider buildings as short term assets • They hire parties to execute design, construction, maintenance and demolition • They focus on profit generation
	Real Estate Investors	• They are involved in the evaluation of the real estate market • They aim to build long-term wealth • They consider sustainable aspects are taken in long-term investments
	Financers	• They are involved in the implementation of evaluation and risk models • They aim to achieve profit maximization across their portfolio • They support the building sector through investments and loans
	Owners	• They consider buildings as an asset • They wish to guarantee both the highest value and operating margin of it • They may also have the role of the user
	Users	• They consider the building as an object that fulfills a spatial need or function • Their demands are directly connected to asset price
	Facility Managers	• They have the responsibility to ensure the high level of operations within a building,
DESIGN & BUILD TEAM	Architects Designers Engineers Consultants	• Their role involves the planning, design, calculation and review of the buildings construction in accordance to a set budget and design requirements.
	Contractors Builders	• They are involved in the construction of individual and multi-unit building projects
SUPPLIERS & MANUFACTURERS	Suppliers Vendors Manufacturers	• They are in charge of the supply of products, components • They are sometimes involved in the provision of services.
	Distributors	• They purchase quantities of goods from producers or vendors and resell these. • Their awareness concerning the sustainability of goods is limited.
	Installation Companies	• They sell and install specialty products in new construction and renovation projects. • They perform maintenance and replacement activities during the operational phase
RECOVERY SPECIALISTS	Deconstruction Companies	• They are in charge of tearing down buildings and the division of waste flows of limited value..
	Demolition Companies	• They take a building apart while preserving the value of elements for enabling their reuse.
	Waste Management Companies	• They are involved in recycling of waste for energy recovery or landfill disposal

GOVERNMENT & CITIES	Regulators & Legislators	• They protect the users, citizens, companies and employees against unfair and adverse impacts. • They have the power to apply measurements which can direct the market • They sustain a linear built environment with sticking to old measures

CIRCULAR BUILDINGS AND THE IMPORTANCE OF BRAND'S "6S" FRAMEWORK

Since this research focuses on the buildings of the Dutch built environment, it is important to provide a definition of circular buildings. A number of different ones have been introduced; however, the definition of circular buildings which will be used for this research is the one of Leising et al. (2018), as it is more comprehensive than the aforementioned one: *"A lifecycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and* ***uses new ownership models*** *where materials are only temporarily stored in the building that acts as a material bank".*

Buildings are constructed of standard manufactured products, but when these are assembled they create a complex, ever-transforming, unique, and long-lived entity. In addition, as suggested by a number of authors the 'manufacture' and useful life phases of a building extend over a significant time span (Pomponi & Moncaster, 2017). These two aspects are clear in Brand's "6S" framework. This framework will be used for this thesis as mentioned in chapter 1.2 since as indicated by researchers (Fischer, 2019; Thelen et al., 2018) in the field of CE for the built environment it:

- Illustrates the different lifespan of each layer
- Highlights the different function of each layer
- Illustrates the long lifespan of the building
- Enables to identify the different products, components and material which assemble each layer
- Enables to distinguish the different decisions made in each layer
- Enables design for modularity since all PCMs are divided in the different layers
- Enables gathering the relevant information and data for the different PCMs in the different layers i.e. where PCMs are and in what state
- CE in the built environment is expected to increase the residual value of PCMs; thus, looking at the value of each layer separately is more suitable rather than the value of a whole building

Schmidt & Austin (2016) based on Brand (1995) mention that Stewart Brand's "6S" framework a buildings consist of distinctive and interlinking layers, each with a different function and lifespan (Figure 1.1). The layers concept was first introduced by architect Frank Duffy in the 1970s, who argued that buildings should not be measured in material terms, but in terms of time (Schmidt & Austin, 2016). Duffy presented the "4S" framework, which divides the building in four shearing layers, namely the Services, Skin, Structure, and Site (Brand, 1995; Schmidt & Austin, 2016). In the 1990s Stuart Brand further expanded by looking at a building as a set of 'shearing' layers that change at different rates, meaning that the more layers are connected, the greater difficulty and cost of adaptation, suggesting the design will be governed by slow changing components, for instance the structure constraints the skin; the skin constraints the services (Schmidt & Austin, 2016). Additionally, Brand added two extra layers, namely the Space Plan and the Stuff (Brand, 1995). Table 2.4 presents and analyzes the six shearing layers of the Brand's "6S" framework (Brand, 1995; Schmidt & Austin, 2016; Milwicz & Palawski, 2018). All shearing

layers has a specific function and consist of distinctive PCMs; thus, in order to formulate each one of them different decisions need to be made, as highlighted in Table 2.4.

Table 2. 4 Explanation of the building's layers and their corresponding decisions
Source: (Brand, 1995; Milwicz & Palawski, 2018; Schmidt & Austin, 2016)

LAYER	EXPLANATION	DECISIONS
STRUCTURE	• Supports the primary transferring of vertical loads and horizontal bracing. It includes foundation, beams, columns, and walls.	• The vertical and horizontal load bearing elements are decided. Structural safety, fire resistance, and environmental impact are taken into account in the decision making.
SKIN	• Protects from external factors. It includes the facade and the exterior	• The cladding, roofing, shading system, the size, type and shape of windows and doors are decided. Moisture and thermal protection are taken into account in the decision making
SERVICES	• Supplies and transports physical flows, namely energy, water, communications. It includes moving parts of the buildings elevators.	• The ventilation, communication, water, heating and cooling systems are decided. Vertical mobility systems are determined.
SPACE PLAN	• Defines the interior layout of the building. It includes the ceilings, floors, and doors.	• The lightning, ceiling, flooring, wall finish system, acoustic design and wall practices are decided.
STUFF	• Refers to the object the users inhabit. It includes furniture, such as chairs, desks, kitchen appliances in the building.	• Decisions regarding furniture are made.
SITE	• Defines the geographical setting, the urban location, and the legally defined lot.	• The site of the building is decided by the owners and planners stakeholder group. Land, price of area and future value are taken into account in the decision making

LIFECYCLE STAGES OF THE BUILDING

The lifecycle of a building significantly differ in the linear and in the circular economy. There are many possible ways of analyzing a building's lifecycle (Peters et al., 2017); however, the one proposed by Rios & Grau (2019) will be used in order to analyze the building's lifecycle in the linear built environment (Table 2.5).

Table 2. 5 The building's lifecycle in the linear built environment
Source: (Rios & Grau, 2019)

LIFECYCLE STAGE	EXPLANATION
RAW MATERIAL EXTRACTION	• For the production of products and components used in buildings raw material is extracted iron ore, limestone, bauxite, copper, timber and petroleum
MANUFACTURING	• The extracted raw material is converted to products and components used in buildings
DESIGN	• The various requirements of both usage and operations of the building
CONSTRUCTION	• The products, components and materials come together on site for the construction of the building.

OPERATION & MAINTENANCE	• The maintenance of the products and systems of buildings is conducted to ensure the continuous performance and operation in a safe, efficient and reliable manner.
END-OF-LIFE	• The demolition of the building is followed by the landfill disposal of individual components and materials. In the linear built environment a small percentage of the components is recycled.

In this context, Figure 2.8 is a schematic representation of the described stages of buildings' lifecycle stages in the linear built environment.

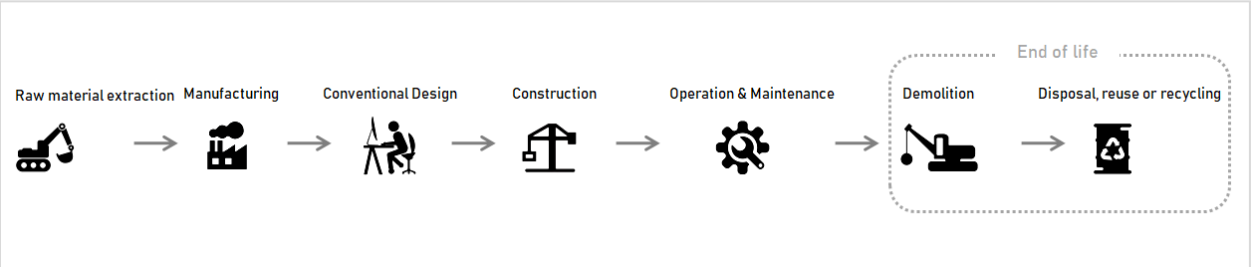

Figure 2. 8 The building's lifecycle in the linear built environment
Source: (Rios & Grau, 2019)

However, moving towards the circular built environment CE principles need to be taken into account in each lifecycle stage of the building (Fig. 2.9) (Rios & Grau, 2019; Adams et al., 2017). According to Rios & Grau (2019) in the design phase the focus is on enabling disassembly, since this will facilitate the reuse of PCMs. The key principles of design for disassembly include:

- Document materials and methods
- Design for production and assembly i.e. modularization and prefabrication
- Design connections to be accessible
- Organize non-reusable and non-reusable products and components
- Standardize products and components

The authors add that design for disassembly principles should be followed both in the construction and deconstruction phase for the buildings' products components and materials. This way the closed loop approach is achieved, leading to the extraction of raw materials, embodied energy and emissions (Rios & Grau, 2019).

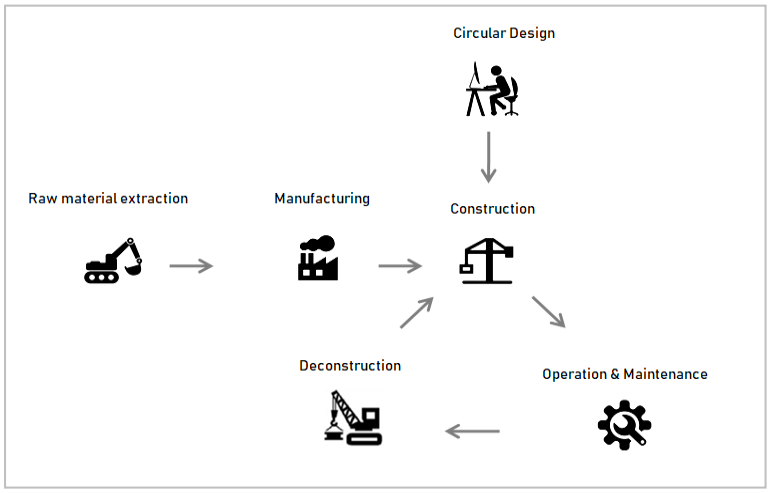

Figure 2. 9 The building's lifecycle in the circular built environment
Source: Source: (Rios & Grau, 2019)

2.4 PRODUCT SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS

2.4.1 CIRCULAR BUSINESS MODELS

The general idea of business models evolved in the 1950s (Planing, 2018). A business model is considered the representation of the underlying core logic of the company (Vermunt, Negro, Verweij, Kuppens, & Hekkert, 2019). One of their main tasks is the creation of a better understanding of the business, since all relevant aspects, such as competitors and changes have a strengthened focus (Planing, 2018). As a result, they facilitate the identification of own weaknesses, and provide the possibility to systematically come up with new business ideas and to analyze them (Planing, 2018). Within a business model, ideas and technology are linked to produce commercial outcomes (Planing, 2018). They increase the flexibility of the company's strategy and help to outline the differentiation from competitors; thus, when they are well structured they are considered a source of competitive advantage (Planing, 2018). Furthermore, the development of the right business models is becoming increasingly important and can be seen as a major success factor for innovative companies (Planing, 2018). Specifically, it has been stated that without a well-developed business model, innovators will fail to either deliver or to capture value from their innovations (Planing, 2018).

There are a number of different ways to define a business model. A definition widely cited is the one of Osterwalder & Pigneur (2010) stating that (Nußholz, 2017; Planing, 2018; Geissdoerfer et al., 2018b; Bocken et al., 2019):*"A business model is the core logic how a company creates, delivers, and captures value".* As can be concluded by the aforementioned definitions and highlighted in the work of Geissdoerfer et al. (2018b) there is a central role of value in most definitions. In addition, another common characteristic among the definitions is the reference to the three dimensions of value which are present in business models, namely: value proposition, value creation & delivery, value capture (Osterwalder, 2010; Nußholz, 2017; Planing, 2018; Geissdoerfer et al., 2018b). Table 2.6 presents the value categories, and each ones corresponding question and definition. The definition which will be used for this thesis is the one of Geissdoerfer et al. (2018b), because it illustrates all dimensions of value and the importance of the interactions between them: *"Business Models are simplified representations of the value proposition, value creation and delivery, and value capture elements and the interactions between these elements within an organizational unit."*

Table 2. 6 Business models' value dimensions
Source: (Osterwalder and Pigneur, 2010)

VALUE DIMENSIONS	CORRESPONDING QUESTION	DEFINITION
VALUE PROPOSITION	• **What** value is proposed and to whom?	• This describes the products or services offered by the company
VALUE CREATION & DELIVERY	• **How** is value created and delivered?	• This describes how value is provided **upstream** in the value chain via partners, resources and activities, as well as **downstream** via specific channels, customer segments and customer relationships

VALUE CAPTURE	• **How** is value captured?	• This describes how the company captures value from its revenue streams and cost structures

A framework widely adopted for the conceptualization of business models due to its practical application is the "Business Model Canvas (BMC)" (Osterwalder & Pigneur, 2010; Nußholz, 2017; Pieroni, McAloone, & Pigosso, 2019), which introduces nine business model elements, and relates them to one of the three value dimensions Figure 2.10.

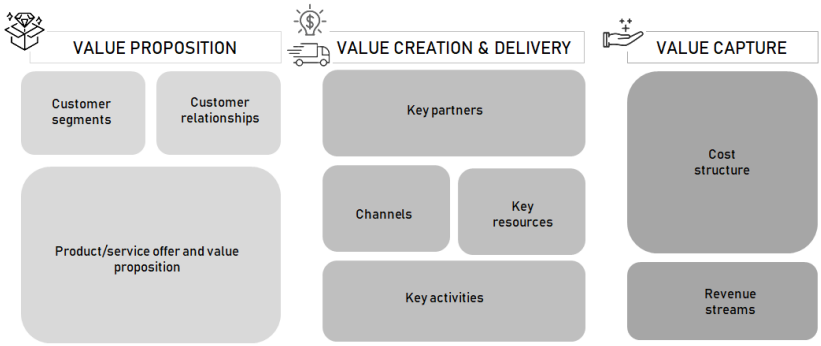

Figure 2. 10 Business Model Canvas
Source: (Osterwalder & Pigneur, 2010)

For the transition towards circular economy, business models are significantly supported for the realization of economic benefits while delivering both environmental and social value (Bocken et al., 2013; Pieroni et al., 2019; Leising et al., 2018; Planing, 2018). Therefore, during the past recent years, policy makers, practitioners, and researchers have increasingly focused on CBMs (Nußholz, 2017). This illustrates, that companies play a key role within this transition, through the development and implementation of CBMs (Vermunt, Negro, Verweij, Kuppens, & Hekkert, 2019).

At this point providing a definition of CBMs is essential since it will clarify the concept's objectives. However, scholars claim that there is no clear definition of CBMs in literature (Nußholz, 2017; Geissdoerfer et al., 2018a). For this study the definition which will be used is the one of Geissdoerfer et al. (2018a):*"CBMs can be defined as Sustainable Business Models (SBMs) - which are business models that aim at solutions for sustainable development by creating additional monetary and non-monetary value by the pro-active management of a multiple stakeholders and incorporate a long-term perspective - that are specifically aiming at solutions for the Circular Economy, by incorporating elements that slow, narrow, and close resource loops, through a circular value chain and stakeholder incentive alignment."* It was chosen because it highlights the sustainability dimension of CBMs, by including in the definition that it is a type of SBM. In addition, it clearly illustrates that the three circular strategies of slowing, closing and narrowing resource loops, which are presented and analyzed in chapter 2.4.3 and are an integral part of CBMs. The CBMs definitions which were examined can be found in APPENDIX C.

Business Model Innovation has been characterized as an enabler for the implementation of circular strategies (Nußholz, 2017; Bocken et al., 2019b); thus it is analyzed in the following section.

2.4.2 CIRCULAR BUSINESS MODEL INNOVATION

Even though the term 'Business Model Innovation (BMI)' is utilized in an increasing number of scientific publications appears to still lack a commonly accepted and generally valid definition (Planing, 2018). A number of researchers, consider it as a process of making changes to existing business models with aim to develop new business model configurations, for instance in a mature company, or creating a new one with the goal to find novel ways to create, deliver, and capture value, such as in a start-up or within a new business area of a mature company (Osterwalder and Pigneur, 2010; Guldmann & Huulgaard, 2020)

In this context the work of Geissdoerfer et al. (2018b) is important, since the scholars managed to develop a definition which not only explains the concepts, but also provides a detailed analysis of the different types of BMI. According to their work business model innovation is *"The conceptualization and implementation of new business models. This can comprise the development of entirely new business models, the diversification into additional business models, the acquisition of new business models, or the transformation from one business model to another. The transformation can affect the entire business model or individual or a combination of its value proposition, value creation and deliver, and value capture elements, the interrelations between the elements, and the value network."* Figure 2.11 provides an overview of the different types of BMI in accordance to the aforementioned definition.

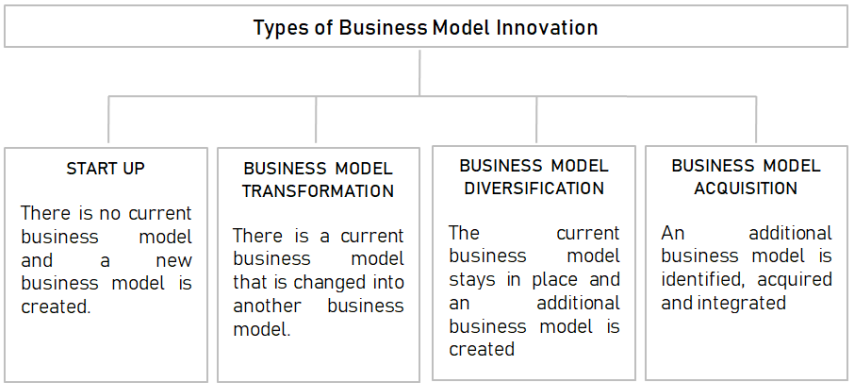

Figure 2. 11 Types of Business Model Innovation
Source: (Geissdoerfer et al., 2018b)

Circular business model innovation (CBMI) is a particular kind of Sustainable Business Model Innovation (SBMI) that aligns with the circular economy paradigm (Bocken et al., 2019a; Guldmann & Huulgaard, 2020). In this context, SBMI incorporates sustainability principles as guidelines for business model design; therefore, it is more sophisticated when compared to the conventional BMI process. The goal of SBMI is not only to capture economic value and to achieve competitive advantage through the generation of superior value for the customer and, but also strive to have a positive contribution to both environment and society (Pieroni, McAloone, & Pigosso, 2019).

As concerns the research on CE-oriented Business Model Innovation or CBMI it is even more recent than SBMI, but over the last year the concept has grown rapidly (Pieroni, McAloone, & Pigosso, 2019). The process of CBMI involves the transformation of an existing business model of a mature company, by

updating its elements, or the creation of an entirely new one which implements and capitalizes on CE principles (Bocken et al., 2019b). Therefore, it aims to enhance both resource efficiency and effectiveness by narrowing or slowing energy and resource loops, and ultimately closing energy and resource flows by changing the perception of economic value and the interpretation of products are approached (Bockenet al., 2016; Nußholz, 2017; Pieroni, McAloone, & Pigosso, 2019).

2.4.3 CIRCULAR BUSINESS MODEL STRATEGIES AND TYPES

According to Nußholz (2017), there are different ways to categorize circular strategies; however, the most widely adopted one is slow, close, and narrow resource loops (Table 2.7) (Bocken et al., 2016; Antikainen & Valkokari, 2016; Nußholz, 2017; Pieroni, McAloone, & Pigosso, 2019):

Table 2. 7 Circular strategies
Source: (Bocken et al., 2016)

CIRCULAR STRATEGIES	EXPLANATION
SLOWING RESOURCE LOOPS	• This strategy aims at the extension and intensification of products utilization is achieved through the design of long-life goods and product-life extension; thus, resulting in a slowdown of the flow of resources.
CLOSING RESOURCE LOOPS	• This strategy aims at closing the loop between post-use and production through recycling
NARROWING RESOURCE LOOPS	• This strategy aims at the reduction of the material utilized in products, thus the same result is achieved with less. This approach does not have an effect on the speed of the flow of products and does not involve any service loops. Narrowing is therefore not an aim of circularity, but is concerned with the reduction of resource use associated with products and processes.

Geissdoerfer et al. (2018a) in their researcher distinguished another two circular strategies, namely intensifying and dematerializing resource loops (Figure 2.12). Even though they are part of slowing resource loops, the scholars argue that it is important to emphasize both the intensification of the use phase – intensifying resource flows – and the substitution of product utility by software and service solutions – dematerializing resource flows. However, for this research the intensifying resource flows and dematerializing resource flows were kept as part of the slowing resource loops.

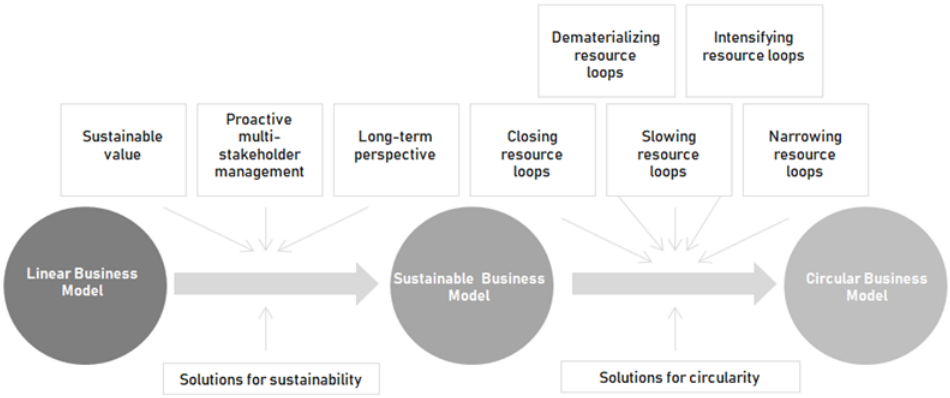

Figure 2. 12 Difference between LBMs, SBMs, and CBMs

Source: (Geissdoerfer et al., 2018)

Literature supports that CE thinking should be incorporated at an early phase in the product design process (Bocken et al., 2016). This can be explained by the fact that once product specification are made, making changes is difficult, since infrastructures, resources, and operations have been determined to a specific product design (Bocken et al., 2016). Requirements to support narrowing the loops should be applied at the manufacturing stage (Nußholz, 2017; Jensen, 2018). Furthermore, considerations for slowing and closing the loop can also be addressed in the design and supported by business models (Jensen, 2018). Therefore, Bocken et al. (2016) building on the two strategies retrieved product design (Table 2.8) and business model strategies (Table 2.9) for CE.

Table 2. 8 Overview of design strategies for slowing and closing resource loops
Source: (Bocken et al., 2016)

DESIGN STRATEGIES **Slowing resource loops**	**DEFINITION**
Designing long-life products *Ensuring and enabling long period of utilization of products and consists of three elements.*	
Design for attachment and trust	• This element refers to design products that will be loved, liked or trusted longer, also known with the term emotional durability.
Design for reliability	• This element refers to design products to operate without failures in case they are maintained in accordance to the instructions.
Design for durability	• This element refers to design products which can resist tear and wear without breaking down.
Design for product life extension *Ensuring the extension of the use period of products, and thus the product life, through service loops, such as reuse, maintenance, repair, technical upgrading and a combination of these. It consists of four elements*	
Design for ease of maintenance and repair	• This element refers to the design of the product in such a way that enables it to be maintained in an optimal condition via inspection and/or servicing/repair.
Design for upgradability and adaptability	• This element refers to design a product with the ability to continue being useful by improving the quality, value, and effectiveness or performance
Design for standardization and compatibility	• This element refers to design products in a way that it fits other interfaces.
Design for disassembly and reassembly	• This element is about ensuring that the product can be dis- and reassembled again, in order to support reuse and recycling of the materials.
DESIGN STRATEGIES **Closing resource loops**	**DEFINITION**
Design for a technological cycle	• This refers to the design products using materials which can be continuously and safely recycled into new materials or products
Design for a biological cycle	• This refers to the design products using safe and healthy materials, which create food for natural systems across their life cycle. In a biological cycle, materials are biodegraded to start a new cycle.
Design for disassembly and reassembly	• This refers to the design of product in such a way to either support the separation of materials, biological from technological or to ensure primary recycling.

Table 2. 9 Business model strategies for slowing and closing resource loops
Source: (Bocken et al., 2016)

BUSINESS MODEL STRATEGY Slowing resource loops	DEFINITION
Access & performance model	• Satisfying user needs with the provision of the capability or services rather than the ownership of a physical product.
Extending product value	• Exploiting the residual value of a product or a collection of products between different business entities
Classic long life model	• Delivering of a long product life supported by design approaches such as design for durability and repair.
Encourage sufficiency	• Reducing end-user consumption with the provision of services, warrantees
BUSINESS MODEL STRATEGY **Closing resource loops**	**DEFINITION**
Extending resource value	• Exploiting the residual value of resources, by collecting material and resources considered waste and convert them into new forms of value
Industrial Symbiosis	• Using residual outputs from one process as input for another process which is in close geographical proximity

Each business model strategy results in a circular business model type (Bocken et al., 2016; Nußholz, 2017; Jensen, 2018). The focus of this research is on product-service systems, also referred as product as a service, which is the circular business model resulting from the access and performance business model strategy for slowing resource loops (Bocken et al., 2016; Bocken & Short, 2016; Nußholz, 2017; Jensen, 2018). According to scholars, PSSs are concerned with the type of business, where the aim is to deliver capability rather than ownership. The service and maintenance part is taken over by the manufacturer, which allows the companies to capture financial benefits from going circular.

As concerns the CBMs in the built environment, different types can only be found in grey literature. Carra & Magdani (2016) categorized the CBMs for the built environment in three main circular strategies, namely circular design, circular use, and circular recovery, and recognized different CBMs for each category. Kubbinga et al. (2017) in their report which focused on the identification of specific possibilities for the application of BMs in the Dutch circular built environment, recognized five types of CBMs: circular inputs, product-service systems, lifetime extension, sharing platforms, and value recovery. A very important contribution in this context is the one of Peters et al. (2017), since their work is part of the buildings as material banks, a co-founded project by the Horizon 2010 Framework Programme of the European Union. In their report the scholars recognized four main circular strategies, namely: product/component/material driven, product performance driven, building performance driven, value network and collaboration driven. All the circular strategies and circular business models types for the built environment identified in the work of Carra & Magdani (2016), Kubbinga et al. (2017) and Peters et al. (2017) can be found in APPENDIX D.

In the chapter 2.5 first an in-depth investigation of product-service systems is provided, followed by an analysis of their application as circular business models.

2.5 PRODUCT SERVICE SYSTEMS

A Product Service System (PSS) is a market proposition that extends the traditional functionality of a product by incorporating additional services (Annarelli, Batistella, & Nonino, 2016). In traditional business

models, the customer purchases a product, and as a result, becomes not only responsible for monitoring its performance, but also for the provision of assistance and assurance of its disposal (Barquet et al., 2017). Instead, PSS includes a systematic combination of selling products as well as services. Specifically, the company still produces the product; however, the ownership of it is not transferred to the customer, and the responsibility for a number of services, such as maintenance, repair, servicing and disposal remains with him/her (Figure 2.13) (Barquet et al., 2017; Kühl et al., 2018; Baines et al., 2007). In return, the customer pays the manufacturer for the use (e.g. pricing time, number of uses) or functionality (performance) of the equipment (Bocken et al., 2016; Barquet et al., 2017; Kühl et al., 2018).

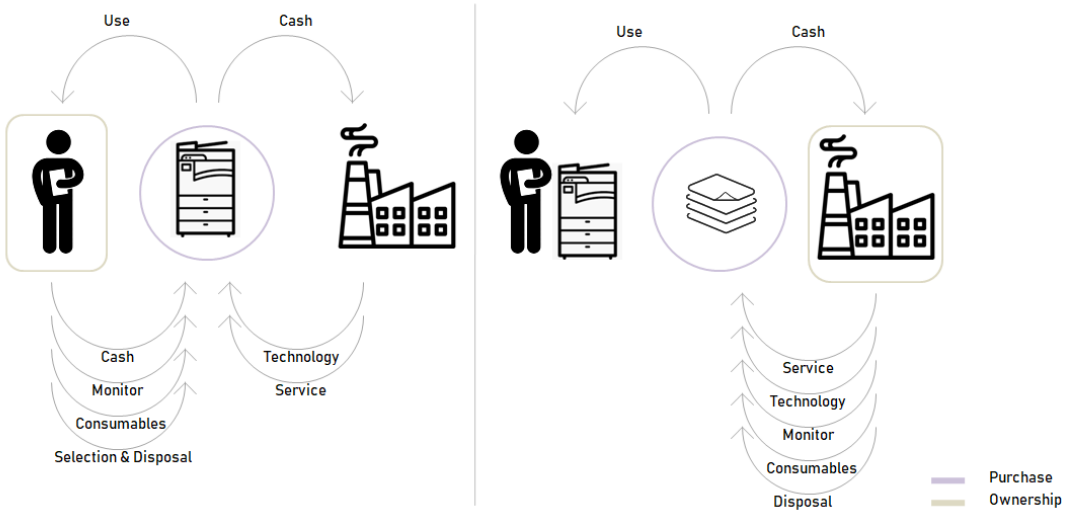

Figure 2. 13 Traditional business model vs Product-Service Systems as a business model
Source: (Baines et al., 2007)

The first definition of PSS appears in the '70s by Rathmell (Pezzotta et al., 2014); however, literature on PSSs began to emerge after the publication of the work by Goedkoop et al. in 1999, who provided one of the most cited definitions, namely: *"PSS is a marketable set of product and services capable of jointly fulfilling a user's need."* Before the appearance of the aforementioned definition, literature was already dealing with a subject closely connected to PSS: servitization (Annarelli, Batistella, & Nonino, 2016; Kristensen & Remmen, 2019), which is the process of manufacturers adding value through the provision of services (Kühl et al., 2018). Product- service system is thus considered a sub-set of this phenomenon, since it also deals with adding value to core corporate offerings through services (Kühl et al., 2018). According to Annarelli et al. (2016), although describing the same concept the difference between PSS and servitization lies in the meaning behind the two terms and in the context in which they are used. The first one is usually utilized when the focus is on the offering's sustainability potentials, while the latter one is mainly used in an economic context (Annarelli et al., 2016).

In spite of the increasing interest of the PSS in academic research, the subject has not yet a comprehensive definition (Beuren et al., 2013). Literature provides several definitions of PSS, each one focusing on particular aspects and/or characteristics (Annarelli et al., 2016). However, according to a number of researchers all definitions of PSS give emphasis to the essential demand of diversified user needs and the essential concept of systems (Annarelli et al., 2016; Michellini et al., 2017; Kühl et al.,

2018; Zhou, Zhao & Hu, 2019). In APPENDIX E an overview of the definitions of PSS is provided. The definition which will be used in this thesis is the one provided by Annarelli et al. (2016), since it is the result of academic research and includes the three pillars of sustainability: "*PSS is a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs.*"

An often applied categorization of product-service systems is the trichotomy of product-oriented, use-oriented and result-oriented PSS (Tukker, 2004; Tukker, 2015; Kuo et al., 2019; Yang & Evans, 2019; Kristensen & Remmen, 2019). The three archetypes introduced by Hockerts and Weaver (2002) are classified according to the ratio of service involved and the ownership of the product (Yang & Evans, 2019):

- **Product-oriented PSS:** The provider sells products and offers additional service, such as maintenance, consultancy, insurance, repair and training.
- **Use-oriented PSS:** The provider retains the ownership of the products and sells the utility, availability or function of products. It includes leasing, renting, sharing and pooling.
- **Result-oriented PSS:** The provider sells the results of a product, so the provider is also the user of the products. For instance, instead of selling air conditioners a company sells comfortable room temperature.

Based on the three archetypes several authors have proposed specific subcategories (Yang & Evans, 2019); however, current studies highlight that there is no consensus which is the best way to categorize PSS (Beuren et al., 2013; Yang & Evans, 2019). Among the different classifications, most of service types proposed by other authors could be fitted into the three archetypes of PSS or eight subcategories of Tukker (2004) (Yang & Evans, 2019). The analysis of the subcategories can be found in APPENDIX F.

In this context, the work of Demyttenaere et al. (2016) is important, since the scholars emphasized in their research comment that the distribution of property rights can closely be linked to the type of PSS offered. They mention that when PSS is service oriented the property rights of the consumer decrease compared to product-oriented PSSs. They further mention that the shift in property rights is generally also linked to a shift in responsibility; hence, they consider that changes in property rights alter the level of responsibility a consumer has over the product-service. They further state that when focusing on pure service provision, a consumer has both no property rights and no responsibility. In addition, Demyttenaere et al. (2016) mention that examining the shift in the temporality of possession is also important. They state that when the PSS is product-oriented PSS there is long-term interaction with an object mainly because of the ownership; instead, in the case of access, possession is more temporary. All these aspects are illustrated in (Figure 2.14).

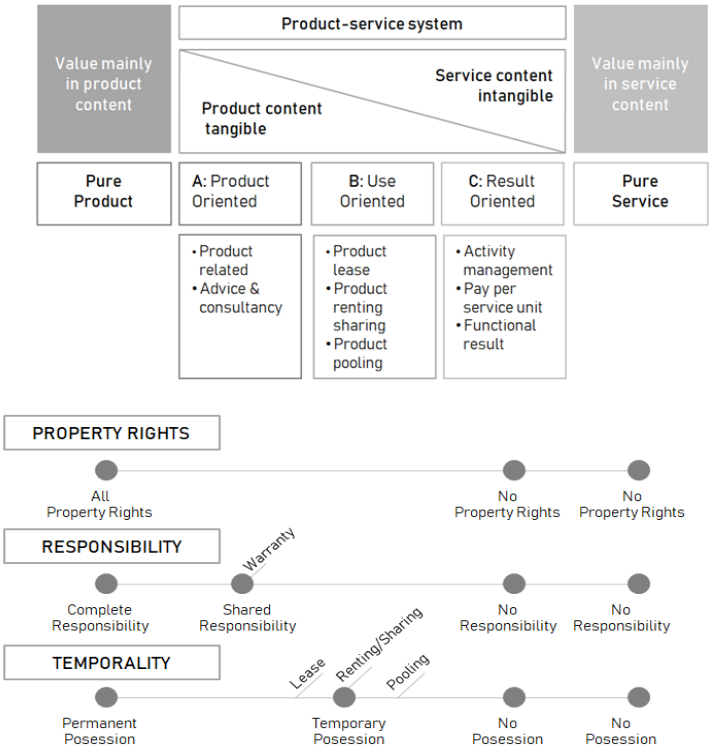

Figure 2. 14 Product-Serrvice Systems and shift in property rights, responsibility, and temporality
Source: (Demyttenaere, Dewit, & Jacoby, 2016)

2.5.1 PRODUCT SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS

To be successfully implemented, circular economy requires the design of innovative business models that can enable multiple value creation mechanisms. In recent years, PSS are regarded as the pioneering business models to shift the production and consumption from the linear model towards CE (Pieroni et al., 2018; Yang & Evans, 2019; Schroeder, Anggraeni, & Weber, 2019). Specifically, according to Kühl et al., (2018) PSS are the most widely cited potential application of CBMs. As illustrated in chapter 2.4.5 access and performance models are contributing to the circular economy by slowing resource loops (Bocken et al., 2016). However, according to scholars product-service systems as circular business models do not only slow but also close material loops. Urbinati et al. (2017) explains that in circular economy the supplier who retains the ownership has the incentive to design products with extensive lifecycle, which consume the least amount of resources and energy during their use phases (slowing resource loops) and which are suitable to be disassembled and recovered at the end of life, thus exploiting its embedded value (closing resource loops) (Urbinati, 2017)

However, PSS is neither inherently circular nor sustainable (Tukker & Tischner, 2006; Michelini et al., 2017; Pieroni et al., 2019). Therefore, if the implementation of PSS for CE needs to be done with great care, since there is no guarantee PSS will reduce environmental impacts, unless be intentionally designed (Michelini et al., 2017). In this context, Michelini et al. (2017) examined whether the PSS model agrees with the principles of circular economy, which were presented and analyzed in chapter 2.2.4:

- **PR1:** Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows

The authors point out that only the performance or result oriented PSS type has the potential to enhance natural capital through the control of finite stocks. In order to explain this, they mention that companies which implement the product-oriented are still incentivized to maximize product sales; thus, the material usage is not constrained. As concerns the use-oriented one, the researchers indicate that it could prompt less careful use. In this context, Michelini et al. (2017) based on Tukker (2015) mention that this could lead to adverse impacts regarding resource and energy consumption rendering circularity difficult to happen. On the other hand, in the result-oriented PSS type, the ownership is retained by the producer who is incentivized to design a system with a lower impact in terms of resource and energy efficiency; therefore the possibility to realize this principle is higher.

- **PR2:** Optimize resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological

The authors mention that firms moving towards more service-oriented PSS types are incentivized to retain the products at their highest value in order to enable their reuse after the product's EoL; consequently, resource yields are optimized through circulation of PCMs. This is possible due to the companies retaining full ownership.

- **PR3:** Foster system effectiveness by revealing and designing out negative externalities

The environmental problems caused by the linear economy model are not resolved only through PSS business model. PSS is not inherently sustainable; thus, there is no guarantee PSS will reduce environmental impacts, unless intentionally designed. For this reason, life cycle assessment (LCA), which considers the material flow "cradle-to-cradle", is acknowledged as an important tool to design the product-service systems for circular economy. This is a way to get some important insights about how products must be designed for continuous recovery.

2.6 THE APPLICATION OF PSS AS CBM IN THE BUILT ENVIRONMENT

In order to facilitate the application of product service systems as circular business models for circular built environment it is important to recognize the barriers hindering its application, as well as the enablers to overcome them. In addition, the opportunities realized from the business models' implementation should be recognized in order to motivate companies to establish it and clients to request and accept it.

2.6.1 BARRIERS & ENABLERS

Barriers are considered the explanation of the reasons which are preventing the application of product-service systems as circular business models in the built environment, whereas **enablers** are the actions or conditions which can promote the application of product-service systems as circular business models in

the built environment. The barriers hindering the implementation of PSSs as CBMs in the built environment, as well as the enablers which facilitate its establishment are related to:

- **The application of CE thinking in the built environment**

In this case in order to recognize the barriers and enablers in this category the work of a number of scholars was reviewed. Specifically, Debacker et al. (2017) focused on the key barriers and opportunities for materials passports and reversible building deisgn, Hart et al. (2019) examined the barriers and drivers in the circular built environment, Adams et al. (2017) investigated the current awareness, challenges, and enablers regarding circular economy in construction, and finally, Rios & Grau (2019) as parts of his research studies also the challenges to CE implementation in the built environment.

- **The application of product-service systems as circular business models**

The work of a number of scholars was reviewed for the purpose of identifying the opportunities, barriers, and enablers concerning the application of product-service systems as circular business models. Two scientific papers, namely Yang & Evans (2019) and Barquet et al. (2013), focused on product-service systems in general. The rest of the literature was based on product-service systems and their application for circular economy. Specifically, Kristensen & Remmen (2019) looked into product service systems and their application to facilitate sustainable production and consumption, as well as to support the transition towards circular economy, and Tukker (2015) examined product services for a resource-efficient and circular economy. In addition, Kühl et al. (2018) investigated the implementation of circular economy principles in PSS operations, Linder & Williander (2017) studied the inherent uncertainties of circular business models and focused on product-service systems, whereas Michelini et al. (2017) researched the role of PSS in conducting the transition from linear to circular economy. Finally, two papers only were identified which looked into the application of product-service systems as CBMs in the built environment; Azcarate et al. (2018) and Rios & Grau (2019). From reviewing these sources the following ways of categorizing the barriers and enablers were found (Table 2.10)

Table 2. 10 The categories of enablers & barriers identified in literature

CATEGORIES OF BOTH ENABLERS & BARRIERS	SOURCE
Related to the client Related to the service provider	Azcarate et al. (2018)
Supply Chain ICT Product design	Kuhl et al. (2018)
Cultural Regulatory Financial Sectoral	Hart et al. (2019)
Legislation & policy Awareness & understanding Manufacture of construction products Design & operating buildings Recovery or raw materials and products	Adams et al. (2018)

Business Economic	
CATEGORIES OF ENABLERS	**SOURCE**
Top down Bottom up	Rios & Grau (2019)

After examining the categories pointed out in the reviewed literature, the following six categories were formed for the purpose of this research:

- **Knowledge & Culture**

This category includes barriers/enablers related to lack of knowledge, skills, information, as well as understanding, awareness and interest regarding. It includes aspects regarding the company's culture and personal beliefs.

- **Policy & Legislation**

This category involves barriers/enablers which are concerned with the regulatory and political environment.

- **Finance & Economic**

This category includes barriers/enablers regarding the construction market varying from investment to raw materials prices.

- **Design & Engineering**

This category involves barriers/enablers which are concerned with the design of buildings, and their products and components, as well as with aspects related to the recovery of materials and products.

As concerns the supply chain and technology categories they were informed in order to provide a clearer classification:

- **Supply Chain**

This category involves barriers/enablers which are related to the supply network activities, partners and management.

- **Technology**

This category involves barriers/enablers, and includes the ones which are related to digital and information technologies. In this context, building information systems, Internet of Things, and sensor technologies are mentioned as enablers, whereas underdeveloped technologies related to the quality check of the material are mentioned as barriers.

The barriers and enablers found in literature which are related to the application of CE thinking in the built environment are presented in Table 2.11, and in total 30 barriers and 29 enablers were identified related to this aspect.

Table 2. 11 Barriers and enablers of CE thinking in the built environment

CATEGORY	BARRIERS	SOURCE	ENABLERS	SOURCE
KNOWLEDGE & CULTURE	Operating in linear economy	Hart et al. (2019) Debacker et al. (2017)	Leadership	Hart et al. (2019)
	Lack of coherent vision	Hart et al. (2019)	Consultation with clients	Hart et al. (2019)
	Lack of accountability	Hart et al. (2019)	Engagement activities	Hart et al. (2019)

	Lack of knowledge	Hart et al. (2019) Adams et al. (2017) Debacker et al. (2017)	Forming long term relationships	Hart et al. (2019)
	Lack of consideration for EoL	Adams et al. (2017)	Systems thinking	Hart et al. (2019)
	Insufficient use of collaboration tools	Hart et al. (2019)	Education	Debacker et al. (2017) Rios & Grau (2019)
	Lack of awareness and interest	Hart et al. (2019) Adams et al. (2017) Debacker et al. (2017)	Creation of trust	Debacker et al. (2017)
	Conservative sector	Hart et al. (2019)	Create a vision	Hart et al. (2019)
	Lack of quality assurance for reclaimed products/materials	Debacker et al. (2017) Hart et al. (2019	Assurance schemes for the quality of secondary materials	Hart et al. (2019) Adams et al. (2017) Debacker et al. (2017) Rios & Grau (2019)
	Long product lifecycles	Hart et al. (2019)		
	Lack of information on PCMs in buildings	Debacker et al. (2017)		
POLICY & LEGISLATION	Lack of fiscal incentives for CE	Hart et al. (2019)	Policy support	Hart et al., 2019
	Conflicting policies for energy and environment	Debacker et al. (2017)	Public procurement	Hart et al., 2019
	Laws and regulations hindering CE	Hart et al. (2019)	Regulatory reform	Hart et al., 2019
	Targets focuses on landfill diversion	Hart et al. (2019)	Fiscal incentives	Hart et al., 2019
	Absence of global consensus on policy support	Hart et al. (2019) Debacker et al. (2017)	Producer responsibility	Hart et al., 2019 Rios & Grau (2019)
			Increase of landfill fees	Rios & Grau (2019)
			Carbon taxes	Rios & Grau (2019)
FINANCE& ECONOMIC	Focus of business on the short term	Hart et al. (2019)	Total Cost of Ownership	Hart et al. (2019)
	High upfront investment	Hart et al. (2019) Adams et al. (2017) Debacker et al. (2017)	Development of higher value secondary markets	Adams et al. (2017)
	Low price of raw materials	Hart et al. (2019)	Financial incentives to use secondary materials	Hart et al. (2019) Adams et al. (2017) Rios & Grau (2019)
	Lack of market mechanisms for product/ material recovery	Adams et al. (2017)	Product-Service Systems	Hart et al. (2019) Debacker et al. (2017) Rios & Grau (2019)
	Low value of products at EoL	Hart et al. (2019) Adams et al. (2017)	Communication of case studies	Hart et al. (2019) Adams et al. (2017)
	Unclear business case	Hart et al. (2019) Adams et al. (2017)		

	Lack of proof of concept	Hart et al. (2019)		
DESIGN & ENGINEERING	Complexity of buildings	Hart et al. (2019) Adams et al. (2017)	Standardization	Hart et al. (2019) Adams et al. (2017) Debacker et al. (2017) Rios & Grau (2019)
	Lack of incentive to design for EoL	Adams et al. (2017)	Prefabrication	Rios & Grau (2019)
	Complexity of disassembly	Debacker et al. (2017)	Modularization	Rios & Grau (2019)
			Design for disassembly	Rios & Grau (2019)
SUPPLY CHAIN	Fragmented supply chain	Hart et al. (2019) Adams et al. (2017)	Development of reverse logistics	Hart et al. (2019)
	Lack of collaboration	Hart et al. (2019) Adams et al. (2017)	Collaboration in the supply chain	Debacker et al. (2017)
	Split incentives in the value chain	Hart et al. (2019)		
TECHNOLOGY	Technical challenges concerning material recovery	Hart et al. (2019)	Collaboration and design tools i.e BIM, material passports	Adams et al. (2017) Debacker et al. (2017) Rios & Grau (2019)
			R&D innovation i.e 3D Printing, IoT, Sharing platforms	Hart et al., 2019

In addition, as has been said, barriers and enablers are also connected to the implementation of product-service systems as circular business models, and these ones are reported in Table 2.9 Regarding this aspect, 25 barriers were identified, along with 13 enablers.

Table 2. 12 Barriers and enablers of PSSs as CBMs

CATEGORY	BARRIERS	SOURCE	ENABLERS	SOURCE
KNOWLEDGE & CULTURE	Less careful usage of products	Michelini et al.(2017)	-	-
	Company's not in favor of constraining customer's freedom	Tukker (2015)		
	Lack of skilled staff and training processes	Azcarate et al. (2018)		
POLICY & LEGISLATION	Lack of supporting regulations	Linder & Williander (2017)	-	-
FINANCE & ECONO...	Higher cost due to design complexity	Michelini et al. (2017)	Identification of the right customer type	Linder & Williander (2017)

	Financial risk due to competitor's high speed of innovation	Michelini et al. (2017)	Creation of closer relations	Linder & Williander (2017)
	High cost of high- quality materials	Tukker (2015)	Long term contracts	Linder & Williander (2017)
	High transaction cost	Tukker (2015)		
	High R&D investment cost	Azcarate et al. (2018)		
	Lower upfront profit	Azcarate et al. (2018)		
	Financial model sensitive to global material & commodities trends	Azcarate et al. (2018)		
	Risk of cannibalization	Linder & Williander (2017)		
	Financial risk due to fashion vulnerability	Linder & Williander (2017)		
DESIGN & ENGINEERING	Design for EoL constrained by material and functionality	Kuhl et al. (2018)	Design for End-of-life	Kuhl et al. (2018)
	Design complexity for refurbishment	Michelini et al. (2017)	Life cycle perspective in product development	Kuhl et al. (2018)
	Lack of consideration for after sales service requirements	Kuhl et al. (2018)	Service personnel and data in the design	Kuhl et al. (2018)
	Product category restrictions	Linder & Williander (2017)	Collaboration for the design	Kuhl et al. (2018)
SUPPLY CHAIN	Required reverse logistics	Michelini et al. (2017)	Deploy facilities close to customer	Kuhl et al. (2018)
	Forecasting the planned and unplanned demand of services	Michelini et al. (2017) Kuhl et al. (2018)	Outsourcing activities	Kuhl et al. (2018)
	Lack of formalization of processes dealing with products upon return	Kuhl et al. (2018)	Develop knowledge and competencies for product delivery	Kuhl et al. (2018)
	Limited capabilities in waste collection and treatment	Kuhl et al. (2018)	Technically skilled staff at customer relationship building	Kuhl et al. (2018)
	High risk of planning for multiple cycles	Kuhl et al. (2018)		
	Limited literature on disposal and product recovery	Kuhl et al. (2018)		
	Unpredictability and unreliability of return flow	Linder & Williander (2017)		
	Partners restrictions	Linder & Williander (2017)		
TECHNOLOGY	-	-	Usage of big data	Kuhl et al. (2018)
			Implementation of IoT	Kuhl et al. (2018)

2.6.2 OPPORTUNITIES

A number of opportunities were identified in literature (Yang & Evans, 2019; Kristensen & Remmen, 2019; Kühl et al., 2018; Azcarate et al., 2018; Linder & Williander, 2017; Michelini et al., 2017; Tukker,

2015; Barquet et al., 2013). The majority of the papers examined did not provide specific categories. However, Azcarate et al. (2018) categorized the opportunities in two main ones, namely the ones offered to the service provider and to the client, which are very similar to the ones provided by Barquet et al. (2013). Following the work Azcarate et al. (2018) and Barquet et al. (2013) the opportunities identified in literature are divided in two main categories:

- Opportunities for the company (Table 2.13)
- Opportunities for the client (Table 2.14)

Table 2. 13 Opportunities offered to the company according to literature

OPPORTUNITIES for the Company	SOURCE	OPPORTUNITIES for the Company	SOURCE
Competitive advantage	Tukker (2015) Yang & Evans (2019) Barquet et al. (2011)	Enhance raw material security	Azcarate et al. (2018)
Improve position in value chain	Tukker (2015)	Increased brand protection	Linder & Williander (2017)
Cost effective	Tukker (2015) Kristensen & Remmen (2019) Linder & Williander (2017)	Resource effective - less waste	Tukker (2015) Yang & Evans (2019) Barquet et al. (2011) Kristensen & Remmen (2019) Kuhl et al. (2018)
Better fulfillment of customer needs	Yang & Evans (2019)	Longer product life	Yang & Evans (2019)
More stable relationship with customer	Kuhl et al. (2018)	Resource efficiency	Yang & Evans (2019) Barquet et al. (2011) Kuhl et al. (2018)
Long-term relationship with customer	Kuhl et al. (2018)	Energy efficiency	Yang & Evans (2019) Barquet et al. (2011)
Stronger customer relationships	Yang & Evans (2019) Linder & Williander (2017)	Intensive use of PCMs	Yang & Evans (2019)
Differentiation	Yang & Evans (2019) Linder & Williander (2017)	Reduced environmental impact	Linder & Williander (2017)
Increased revenues	Yang & Evans (2019)	Dematerialization	Yang & Evans (2019)
Identification of new markets	Yang & Evans (2019) Barquet et al. (2011) Azcarate et al., 2018	Freedom to design for sustainability	Yang & Evans, 2019
Reduced risk	Yang & Evans (2019)	Access to service data	Yang & Evans (2019) Barquet et al. (2011) Kuhl et al. (2018) Azcarate et al. (2018)
Reduced lifecycle cost	Yang & Evans (2019)	Improved technology	Yang & Evans (2019)
Alternative to mass production	Barquet et al. (2011)	Keep track of product	Kuhl et al. (2018)
Improvement in the total value delivered	Barquet et al. (2011)	Incentivize innovation	Azcarate et al. (2018)
New revenue stream	Kuhl et al. (2018)	Incentivize quality	Azcarate et al. (2018)
Stable cash-flow	Azcarate et al. (2018)	New job creation	Yang & Evans (2019)

Reduce impact of real estate cycles	Azcarate et al. (2018)	Improved customer behavior understanding	Linder & Williander (2017)
Higher profit margin for services	Azcarate et al. (2018) Linder & Williander (2017)	Incentivize closed loop management	Rios & Grau (2019)

Table 2. 14 Opportunities offered to the client according to literature

OPPORTUNITIES for the Client	SOURCE
Better customer experience	Tukker, 2015
Lower cost	Tukker, 2015
Higher intangible value to the user	Tukker, 2015
Higher customization	Barquet et al., 2011 Kuhl et al., 2018
Higher quality	Barquet et al., 2011
New functionalities	Barquet et al., 2011
Now burden of ownership-Responsibility for monitoring end of life tasks	Barquet et al., 2011 Kuhl et al., 2018 Rios & Grau, 2019 Yang & Evans, 2019
High efficiency	Rios & Grau, 2019
Sustainable alternative	Rios & Grau, 2019
Low investment cost	Rios & Grau, 2019

2.7 BUSINESS MODEL FRAMEWORKS FOR CIRCULAR ECONOMY AND SERVITIZATION

For the establishment of product-service systems as circular business model the examination and implementation of both servitization and circularity principles are needed. This is because, as pointed out from the literature review, product service systems may be considered as a circular business model type; however, PSSs are not circular unless intentionally designed. For this reason, literature was examined with the aim to identify business model frameworks which clearly present the characteristics required for establishing product-service systems and circular business models, and could be utilized for the case study survey of this research. From this review four business model frameworks were identified as potential ones, namely (1) the Sustainable Circular Business Model Innovation by Antikainen & Valkokari (2016), (2) the Circular Business Model framework by Nussholz (2017), (3) the Circular Business Model Canvas by Lewandowski (2016), and (4) the Business Model Canvas for PSS adoption by Barquet et al. (2013).

Antikainen & Valkokari (2016) recognized that a large number of business modeling frameworks and tools don't address some necessary and pre-required elements to facilitate business model innovation for CE. Therefore, in their work the researchers develop a framework (Figure 2.15) based on the business model canvas for sustainable circular business model innovation. The researchers decided that it is important to include three additional elements, namely (1) trends and drivers recognition at the ecosystem level, (2)

understanding value to partners and stakeholders within a business, and (3) sustainability and circularity impact evaluation.

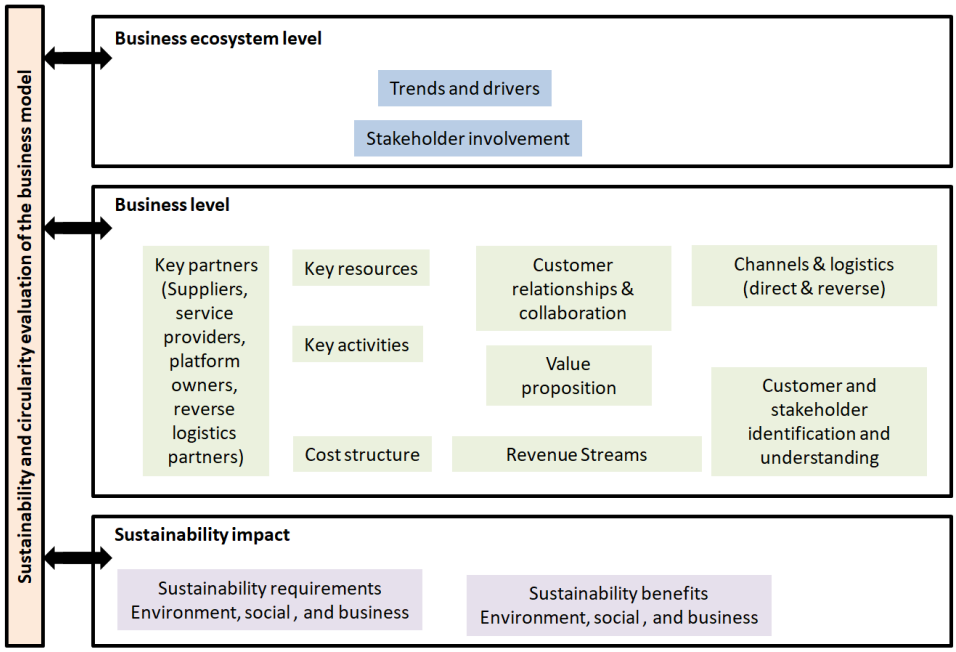

Figure 2. 15 Sustainable Circular Business Model Innovation
Source: Own Image (Antikainen & Valkokari, 2016)

Nussholz (2017) recognized the lack of business model frameworks which focus on specific points of opportunity of the product lifecycle. In order to address this, the researcher in her work develops a framework which connects CE principles and value added from resources cycling based on the traditional business model canvas elements (Figure 2.16)

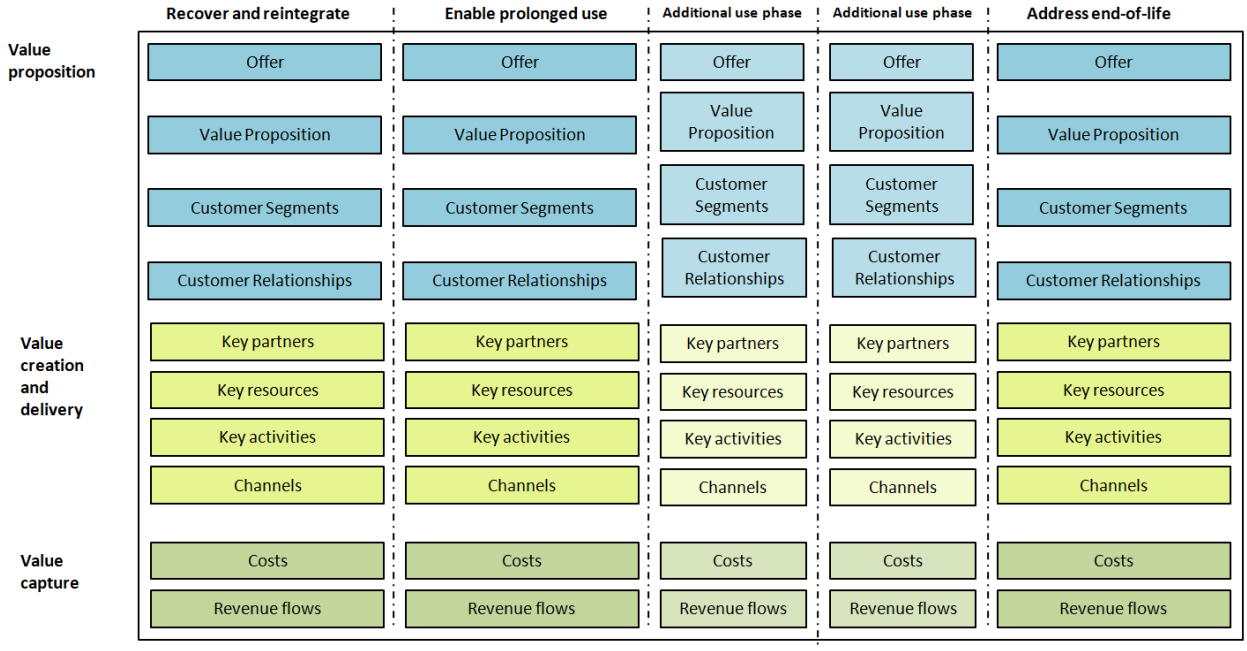

Figure 2. 16 Circular Business Model framework
Source: Own Image (Nussholz, 2017)

Lewandowski's (2016) aim was to find the answer to the following question: "*How the principles of the circular economy can be applied to a business model, and which universally applicable components are needed for a circular business model?*" The business model canvas is based on nine elements; however, the author decided to add two more building blocks in order to incorporate CE principles to the business model canvas, namely (1) Take-back systems, which is based on the fact that CE requires both reverse and forward logistics to be functional in a company, and (2) Adoption factors, which can be either internal or external factors with a positive or negative influence on the circular business model. Moreover, the author included all CE characteristics required in the business model, which can be observed in Figure 2.17.

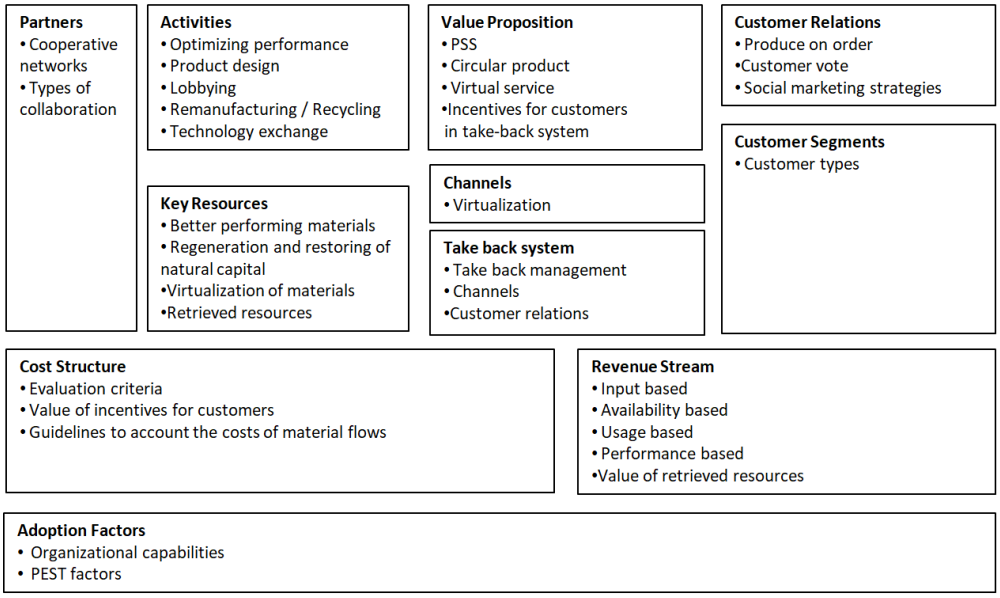

Figure 2. 17 Circular Business Model Canvas
Source: Own Image (Lewandowski, 2016)

Barquet et al. (2013) based on the traditional business model canvas as well as Tukker's (2004) work on the eight PSS types, developed a framework (Fig. 2.18) which aims to support the adoption of product-service systems. The scholars included the product-service characteristics suggested to be taken into account for the design of more service-oriented business model element.

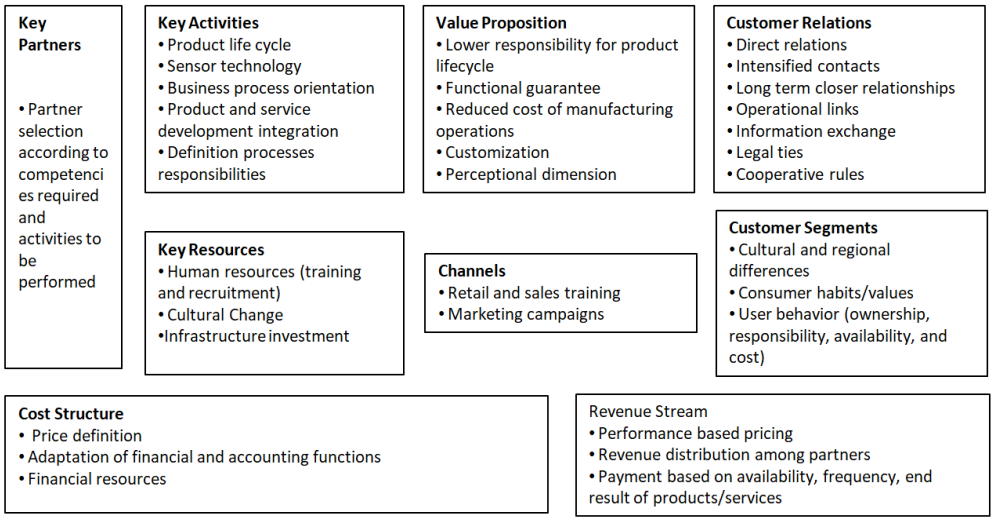

Figure 2. 18 Business model canvas for PSS adoption
Source: (Barquet et al., 2013)

All of the frameworks chosen to be examined are based on the business model canvas, mainly because of its ease in practical application, complexity of components, worldwide recognition, and previous contributions to the development of circular business models (Lewandowski, 2016). According to Bocken et al. (2019), who conducted a review and evaluation of circular business model innovation tools, mentioned in their research that Antikainen & Valkokari's (2016) framework requires further development and refinement. As concerns, Nussholz (2017) as aforementioned it takes a lifecycle approach for the development of her framework. In this context she considers important to architect the business model elements for each phase; however, the framework does not depict the CE characteristics which are needed for the development of a circular business model; thus, it is not suitable for the purpose of this thesis. For the analysis of the companies' business model a framework which incorporates both the circularity and the servitization characteristics required in each business model element is needed. Therefore, Lewandowski (2016), who has included CE principles in the traditional business models canvas, and Barquet et al. (2013), who has integrated PSS characteristics in the elements of the business model canvas, will be combined and used as the case study framework.

2.8 CONCLUSIONS

Literature recognizes the importance of CE and its potential to decouple economic growth from resource consumption which can be achieved by closing the resource loops. The significance of closing the loop was also confirmed by the fact that it is the common characteristics among CE definitions. Another finding was that scholars point out that CE should have a contribution on sustainable development. However, the review illustrated that currently the main focus is on the economy and the environment; thus, the contribution to society is often neglected.

As concerns the built environment, its significance was illustrated, since all of its individual elements affect both the built and natural environment, as well as human-environment relationships. Regarding the Dutch built environment, literature indicated that the main aim of CE thinking in the sector is to

decrease the rate of downcycling products and materials. In addition, it was pointed out that its principles if applied during all lifecycle stages of the buildings can result in numerous benefits varying from both energy and CO2 reductions, to quality improvement and cost reduction. However, it was highlighted that CE practices in the Dutch built environment are not yet accepted.

The examination of current literature on CE for the built environment illustrated the importance of examining the stakeholders' interests since they are the ones who will drive this shift. What can be observed is that currently the actors' decisions are based on money and risk, whereas sustainability and circularity are rarely taken into account. Another main point of the literature review was the significance of circular buildings, whose definition illustrated the need for new ownership models for the PCMs in buildings. In addition the need to change how the lifecycle stages of the buildings are approached was highlighted moving from the linear to the circular built environment. Specifically, the importance of incorporating design for disassembly principles to achieve a closed loop approach was noted.

The review conducted also illustrated the importance of business models' role for the establishment of circular economy. It specifically pointed out that an increasing focus towards circular business models is noticed in scientific literature, which also highlights the companies' role in the transition. In addition, current literature considers circular business models as a subcategory of sustainable business models, and their main difference is that CBMs incorporate strategies which aim to close, slow, and narrow resource loops. In this context, it the importance of addressing these strategies in the design of products and supporting them by business models was illustrated. Moreover, each business model strategy results in different circular business models types. In this respect, the review indicated that different CBM types for the built environment are indicated only in grey literature.

One of the most promising business models for circular economy, as noted both in grey and academic literature, are product-service systems, which involve a systematic combination of selling products and services, and propose the ownership to be retained by the producer. Three types of PSS were indicated based on the ratio of service and ownership, namely (1) product-oriented, (2) use-oriented, and (3) result-oriented; each of them leads to a different distribution of property rights and responsibility. In this context, the result-oriented one was found to be the most promising one for CE. Furthermore, it was shown that PSSs as CBMs slow resource loops through product life extension, and close resource loops through disassembly, recovery at the EoL, and reuse; thus, their embedded value is exploited. However, PSSs are neither inherently circular nor sustainable unless intentionally designed in accordance to CE principles, and the review indicated that the LCA is considered an important tool to support this.

The application of product-service systems as circular business models in the circular built environment is related to barriers and enablers due to the implementation of (i) CE thinking in the built environment and (ii) PSSs as CBMs. The literature review pointed out 30 barriers and 29 enablers related to the first aspect, and 25 barriers were identified, along with 13 enablers related to the second one. Subsequently, six categories of barriers and enablers were formed, namely: knowledge & culture, policy& legislation, finance & economic, supply chain, design, technology. This fact illustrated that for the implementation of

PSSs as CBMs in the circular built environment change needs to be implemented in all these different areas.

The examination of the barriers identified in literature several ones were related to both the application of CE thinking and the implementation of product-service systems as circular business models. The lack of knowledge either in terms of staff and training processes for the establishment of the business model or circular economy in general, as well as the lack of supporting regulations, and the fragmented supply chain were some of the ones in common. What is more, the high investment cost, the difficulty of designing for EoL, along with the design complexity were also barriers indicated in both literature related to the circular built environment and PSS as CBM. As concerns technological barriers no common ones were found. Finally, as concerns the enablers the ones which were in common are related to IoT and its implementation for data collection.

The application of product-service systems are circular business models offers a number of opportunities to both the client and the company, and it can be concluded that the opportunities for the company are closely related to the ones offered to the client. For instance, on the one hand the application of PSSs as CBMs enables producers to access service data which incentivizes both innovation and quality; as a result the final product-service is in terms of quality higher.

Finally, according to the literature review, there are a number of different business modeling tools which are focused on either circular business models or product service systems. From the ones identified only one, namely Lewandowski's (2016), focused on circular business models and referred also to product-service systems. Therefore, the development of a framework which illustrates the CE and servitization characteristics is required for the development of product-service systems as circular business models. This can be achieved by combining Lewandowski (2016) and Barquet et al. (2013) work, based on which the case study framework of this thesis was formulated.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter the methodologies required for addressing the second and third research questions of this thesis are presented and analyzed, namely:

- SRQ2: What are the opportunities, barriers and enablers regarding the application of product-service systems as circular business models in the Dutch built environment?
- SRQ3: How have suppliers in the Dutch built environment successfully established product-service systems as circular business models for products, components, and materials in the building layers?

First the expert interview methodology is defined; its steps are presented and how they were approached for this research is explained. Next, the case study methodology is discussed, and the design for this research is presented. Attention is also paid on the formulation of the case study framework which was used for the purpose of this research.

3.2 THE EXPERT INTERVIEW METHODOLOGY

3.2.1 DEFINITION AND EXPLANATION OF THE EXPERT INTERVIEW METHODOLOGY

An expert interview is a kind of individual interview carried out between an interviewer and a respondent, who is a specialist in the subject in question (Libakova & Sertakova, 2015). According to Meuser & Nagel (2009) a person is addressed as an expert because it is assumed that she or he has knowledge, which she or he may not necessarily possess alone; however, this knowledge is not accessible to everybody in the under study field (Meuser & Nagel, 2009). The purpose of the expert consultation is the discovery of this knowledge, the acquiring of unknown and reliable information, authoritative opinions, as well as professional assessments of the research topic. It is also supported that it allows the provision of information which is difficult to be explored by other methods (Van Audenhove, 2007; Bogner et al., 2009). Moreover, even though the literature review is the basis of the research and knowledge gathering, the expert interviews work as a tool to overcome the limitations of scientific research papers, by linking theory with the real current state of the studied field in a balanced way (Van Audenhove, 2007; Bogner et al., 2009). Finally, in order to allow the expert to share their point of view on the topic under investigation semi-open questions are posed; thus, the expert interviews are mainly semi-structured (Libakova & Sertakova, 2015).

3.2.2 EXPERT INTERVIEW DESIGN

The procedure for the expert interviews consists of several stages. According to Libakova & Sertakova (2015) six steps can be distinguished:

1. Choice of research topic
2. Preparation and planning
3. Interview
4. Transcription of records
5. Analysis and interpretation of data
6. Preparation of the report

In the following section each step will be presented how it was approached for the purpose of this thesis will be analyzed.

1. *Choice of research topic*

This step is the starting point of the expert interview process, mainly because the choice of specialists depends largely on the main subject of the research. Therefore, the topic under investigation, as well as the formulation of a concrete research question must be defined in advance.

The central theme of this research is the application of the product-service systems as circular business models in the Dutch built environment. As aforementioned, the primary aim of the expert interviews was answering the second sub-research question formulated for the purpose of this research, namely*: "What are the opportunities, barriers and enablers regarding the application of product-service systems as circular business models in the Dutch built environment?"*

2. *Preparation and planning*

In order to conduct the expert interviews the researcher needs to be knowledgeable in the subject and have a clear view on what is being investigated (Libakova & Sertakova, 2015). For this reason an extensive literature review was conducted in chapter 2, which enabled the researcher to gain deep understanding regarding the topic under investigation. This was not only important to conduct the expert interviews, but also to analyze them.

A significant part of the preparation for the expert interviews was the development of the interview questionnaire which can be found in APPENDIX G. Its questions were formulated with the aim to cover the following topics:

- Current state and main developments of circular economy in the Dutch built environment
- Suppliers view on the application of product-service systems as circular business models
- Identification of cases where the product-service systems as circular business model has been applied in the Dutch built environment.
- The opportunities, barriers and enablers of the implementation of product-service systems as circular business models in the Dutch built environment

Another significant part of this step was the selection of experts. Sampling is of high importance for the research, since in case the data is not collected from the people which can lead to the provision of valid and reliable answers, the research will be faulty. According to Sekaran & Bougie (2016), in qualitative research sampling begins with the definition of the target population and the non probability sampling technique is most commonly employed. The sampling method utilized in this research was the judgment sampling and it was selected based on the choice of sampling design by Sekaran & Bougie (2016), which can be found in APPENDIX H. The judgment sampling includes the selection of individuals who are in the best position to provide the information required. It is mainly utilized when a low number or a specific category of people have the information that is sought; however, it has the disadvantage of curtailing the results' generalizability (Sekaran & Bougie, 2016)

For the selection of the experts it is important to identify the right specialists; thus a list of criteria was established (Table 3.1). The first five criteria were found in literature, specifically in the work of Libakova & Sertakova (2015), whereas the last one was created by the researcher of this study. In APPENDIX I a thorough analysis of each criterion can be found

Table 3. 1. Selection criteria for expert interview
Source: (Libakova & Sertakova, 2015)

CRITERIA FOR SELECTION	EXPLANATION OF CRITERIA
Related to the research topic	• CE, CBMs, and/or PSS in the Dutch built environment
Educational background	• Different backgrounds for diversity
Work experience	• Multidisciplinary for diversity
Position	• Different experience levels for diversity
Level of public recognition	• Different levels of public recognition for diversity
Country	• Netherlands (preferably)

The selection of the experts was made from different sources while applying the aforementioned criteria. The sources used for the identification of the experts (Table 3.2) were from both academic and grey literature, from scanning the experts' profiles on LinkedIn or from research centers', companies' (construction, consultancy, banks, suppliers of building products, components, and materials), and university departments' websites. In addition, a number of experts were identified from events and conferences which focused on circular economy. Moreover, the snowballing sampling method was utilized, which allows the identification of additional experts from the network of the ones already interviewed who generally possess similar characteristics (Palinkas et al., 2015). As a result, the network of the experts was used as a valuable source for the identification of potential interviewees.

Table 3. 2 Sources for the selection of experts

SOURCES FOR THE SELECTION OF EXPERTS
Academic and grey literature
LinkedIn
Events and conferences
Companies' websites
Governmental websites
Universities websites
Network of experts

After the identification of the experts, an invitation for participation was sent to the candidates in their personal e-mail or, in case the personal e-mail was not available, a personal message was sent to them on LinkedIn.

As concerns the sample size, for the purpose of this research 13 experts were interviewed from 11 different companies and institutions active in Circular Economy and the Dutch Built Environment (Table 3.3) which can was considered sufficient since according to literature, a sample size of at least 12 is required to reach thematic saturation (Picariello et al., 2017).

Table 3. 3 Expert interview participants

EXPERTS	ROLE	STAKEHOLDER TYPE
A	• Project Manager Circular Finance / Circular Economy	• Consultant
B	• Consultant Circular Economy / Rebel Group	• Consultant
C	• . Sales Manager for M-Use Elevators / Mitsubishi	• Supplier
D	• Director / New Horizon Urban Mining	• Urban Miner
E	• Architect / DOOR Architects	• Architect
F	• Construction Specialist / C-Cretaors	• Consultant
G	• Project Manager / TU Delft	• Researcher
H	• Senior Economist Construction & Real Estate / ING	• Economist
I	• Professor of Transport & Logistics / TU Delft	• Academic
J	• Sales Manager for Façade-as-a service / ODS Jansen	• Supplier
K	• Program Manager Circular Economy / Ministry of Infrastructure and Water Management	• Regulator/Legislator
L	• Program Manager Circular Economy / Ministry of Infrastructure and Water Management	• Regulator/Legislator
M	• Associate Professor of Real Estate Management / TU Delft	• Academic

3. Interview

This stage involves the execution of the expert consultation. In direct semi-structured interviews the researcher poses a number of questions to the expert in accordance to the predetermined interview questionnaire; however, the expectations of how they are going to be answered by the respondent are unclear and in the course of the conversation the researcher can decide whether there is need for additional questions (Libakova & Sertakova, 2015).

For the purpose of this thesis, the interviews were conducted by phone call, video call, or face to face. In order to prepare for the interview the advantages and disadvantages of each category were investigated by examining the work of Lo Iacono et al. (2016) and Opdenakker (2006), and an overview of them can be found in APPENDIX J. As concerns this research, only one interview was not conducted with one of the aforementioned methods, since one of the experts requested the interview questionnaire and sent it back with the answers filled.

4. Transcription of records

In this step the relevant parts of the recorded interview data are transcribed from an audio to a text format. In order to record the interviews, the permission of all participants was asked, for ethical as well as legal reasons as explained in chapter 3.3 research ethics.

5. *Analysis and interpretation of data*

For this step the work of Creswell (2014) on the data analysis of qualitative research was utilized. The scholar proposed a number of sub-steps which are schematically represented in APPENDIX K. Firstly, the data was organized and prepared for their analysis; secondly, in order to get a general sense of the information, all transcribed interviews were read through; and thirdly, the data was coded. According to Rossman & Rallis (2012) in Creswell (2014), coding can be defined as "the process of organizing the material into chunks or segments of text before bringing meaning to information". In order to facilitate the process of categorizing the experts' answers part of chapter 2 was devoted to the identification of how scholars categorize the opportunities, barriers and enablers of the application of the product-service systems, as well as the application of CE thinking in the built environment. Finally, the researcher focused on the examination and interpretation of the expert interviews.

6. *Preparation of the report*

The final step of the expert interview is the inclusion of the findings the final research report and it is utilized for answering the research questions.

3.3 THE CASE STUDY METHODOLOGY

3.3.1 DEFINITION AND EXPLANATION OF THE CASE STUDY METHODOLOGY

A general definition of a case study is the one provided by Yin (2003): *"an empirical enquiry that investigates a contemporary phenomenon within its real-life context, where the boundaries between the phenomenon and context are not clearly defined, and in which multiple sources of data collection are used."* Baxter & Jack (2008) based on Yin's (2003) mention that one of the criteria based on which the case study methodology should be chosen for a research is when "*the focus of the study is to answer "how" and "why" questions*", which applies for the purpose of this thesis, since the focus of the case study method is to provide an answer to the fourth sub-research question, namely:*"How have suppliers in the Netherlands successfully established product-service systems as circular business models for products, components, and materials in the building layers?""*

Case studies are considered suitable when a researcher seeks to gain understanding of certain phenomena, and are useful in applying solutions to current problems based on past problem-solving experiences and in generating further theories for empirical testing (Merriam, 2010; Sekaran & Bougie, 2016). Additionally, the method is based in "lived reality", which means that case studies allow the in-detail study of experiences of individuals, groups, or organizations (Sekaran & Bougie, 2016). As concerns this research, the qualitative case study methodology was used for the in-depth investigation of the application of product-service systems as circular business models by companies active in the built environment.

3.3.2 THE CASE STUDY DESIGN

In order to ensure the quality of this research the case study design is in accordance to the work of Baxter & Jack (2008) who indicated four main steps for the case study design:

1. Unit of analysis
2. Determination of the type of case

3. Binding the case
4. Single case study or multiple case study

The explanation of each step is based on the work of Gustaffson (2017), Baxter & Jack (2008), and Yin (2003) and can be found in APPENDIX L. Table 3.4 explains how the case study design steps have been applied for the purpose of this study.

Table 3. 4 Case study design steps

CASE STUDY DESIGN STEPS	EXPLANATION
UNIT OF ANALYSIS	The product as a service as a circular business model of building product, component, and materials suppliers active in the Dutch built environment.
DETERMINATION OF THE TYPE OF CASE	The exploratory type is suitable since the aim is to explore the PSS CBM and map its elements.
BINDING THE CASE	The boundaries were determined by definition and context: • Definition The type of business model which will be studied is the product as a service as a circular business model. No other type of will be studied. • Context The building product, component, and materials suppliers' companies are located and active in the Dutch built environment.
SINGLE CASE OR MULTIPLE CASE STUDY	The multiple case study design was chosen, since the aim is the analysis of the business model of companies supplying building PCMs in the Structure, Skin, and Services layers.

A multiple case study is conducted when more than one single case are examined. According to Baxter and Jack (2008) based on Yin (2003) multiple case studies can be used for the prediction of similar results or for the identification of differences between the cases. This advantage offered by the application of the multiple case study is important since the aim is to explore the similarities and differences of companies which have applied product-service systems as circular business models in the built environment, but also the investigation of whether the similarities and differences resulting from the focus of the companies on different layers of the building. As a result, all the companies chosen have applied the PSS CBM in the built environment and are providing products in different layers of the building. For instance, Mitsubishi is focused on the Service Layer of the building, and provides elevators as a service; whereas, Alkondor Hengelo is focused on the Skin Layer of the building, and provides facades as a service.

In addition, a researcher chooses to study multiple cases when he/she wishes to ensure representativeness (Gustaffson, 2017). This study aims to explore the differences and similarities of the PSS CBMs applied by suppliers active in the Dutch built environment depending on which of the building's layers (skin, structure, and services) the product was intended to be used. As a result, the chosen cases have to represent each of the layers. Finally, the choice of the multiple case study method was strengthened by Gustaffson's (2017) argument that multiple case studies enable the creation of a more credible theory since the results are based on several empirical evidence, which is of high importance when taking into account that the application of product-service systems as circular business models in the Dutch built environment is not the mainstream.

The application of multiple case study method is illustrated in APPENDIX M based on Yin (2003), and is divided in three main parts:

- **STEP1:** Define and design
- **STEP 2:** Prepare collect and analyze
- **STEP 3:** Analyze and conclude

Each step is presented and analyzed in the following section.

- ***STEP1:*** *Define and design*

This step includes the (i) theory development, (ii) case selection, and (iii) the design of the data collection protocol.

i. Theory development

Theory development is an essential part of the preparation for a case study. It involves the reviewing literature relevant to the topic under investigation (Yin, 2003). As concerns this research, chapter 1 and 2 are dedicated to the identification of the knowledge gaps addressed by the case study and the literature review examined the relevant concepts and theories.

ii. Case selection

The next phase of this step is the selection of the cases, which was based on the purposeful sampling method was chosen. According to Seawright & Gerring (2008), the purposeful sampling make an important contribution to the case survey, since they allow the researchers to choose the most appropriate cases in accordance to the research strategy. The purposeful sampling has 16 distinct strategies (Shakir, 2002), and the most suitable one for this research is the criterion sampling strategy, where cases are chosen based on a set of predetermined criteria.

The criteria for the case selection are listed and shortly explained in Table 3.5. They were formulated based on the work of Cha (2017), and two additional ones were formulated by the researcher, namely the Industry, since the focus of this thesis is the Dutch building industry, and the Layer of the building. The latter one is because the aim is to conduct cases with companies which supply products, components and material for one of the layers, namely the structure, skin, and services layer. This criterion aligns also with the need for further investigation for the implementation of product-service systems as circular business models for products, components and materials in the different levels of the building, such as the Structure, Skin and Services layers.

Table 3. 5 Criteria for case selection

CRITERION	DETAILS
Type of CBM	• PSS
Location	• Netherlands
Technology	• Technology-based
Maturity	• Existing customers
Industry	• Building
Customer	• B2B & B2C
Layer of the Buildings	• Structure, Skin & Services

The sources for the case selection were academic and grey literature, and websites, such as Holland circular hotspot, CE-100, and Nederland Circulair. Furthermore, cases were identified through the researcher's network and from the expert interviews. Most of the cases identified were companies which have applied the product-service as a service as a circular business model (Table 3.6); however, a number of project which may have product, components and materials serviced were also found in literature and/or indicated by experts (Table 3.7).

Table 3. 6 Cases of companies

COMPANY/ORGANIZATION	EXPLANATION	LAYER	SOURCE
Madaster	• Platform as a service	-	Researcher's network
TU Delft	• Façade as a service	Skin	Literature & Websites Expert B Expert G
SUNPOWER	• Solar panels as a service	Skin	Literature & Websites
Philips	• Light as a service	Space Plan	Expert B Expert G
Ledlease	• Light as a service	Space Plan	Literature & Websites
Lunera	• Light as a service	Space Plan	Literature & Websites
Desso	• Carpets as a service	Space Plan	Literature & Websites Expert B
Interface	• Carpets as a service	Space Plan	Literature & Websites
Bundles	• Washing machines as a service	Stuff	Literature & Websites Expert E
The Dutch mountains	• Buildings as a service	-	Literature & Websites
Twynstra Gudde	• Real estate as a service	-	Literature & Websites
M.J.Oomen	• Water as a service	Services	Literature & Websites
Eneco & Delta Development	• Climate as a service	Services	Literature & Websites
Mitsubishi	• Elevators as a service	Services	Literature & Websites Expert C Expert G
Spaces 4 You	• Interior walls as a service	Space plan	Expert H
THE FCTR-E	• Energy as a service	Service	Expert A
Kloeckner	• Façade as a service	Skin	Expert J
Ahrend	• Furniture as a service	Stuff	Expert B
Alkondor Hengelo	• Façade as a service	Skin	Expert D

Table 3. 7 Projects were companies with PSS CBM may have been involved

PROJECT	SOURCE
ABN AMRO Circl in Amsterdam Zuid	Literature & Websites Expert A
Park 20|20 in Hoofddorp	Literature & Websites Expert A
Concept village in Rotterdam	Expert I
Erasmus MC in Rotterdam	Expert I
Greenhouse pavilion in Utrecht	Literature & Websites

	Expert H Expert E
Town hall in Venlo	Literature & Websites Expert H

From the company cases which were illustrated in Table 3.6 priority was given to the ones which focused on the Structure, Skin and Services layer. As concerns the Structure layer, no cases were found, whereas four were indicated for the Skin and three for the Services. All of these seven companies were invited for participation; however, a case study interview was conducted only with Mitsubishi Elevators Europe, whereas the other companies either did not respond to the invitation or were not available for a case study interview within the thesis time frame. As concerns the companies which have applied the PSS CBM for products in the Stuff or Space Plan layers they were as well contacted; however, only one reply was received and was available for a case study interview out of the thesis time frame. As a result, the case which was based on an interview is the one of Mitsubishi Elevators Europe and concerns the Services layer of the building. In order to carry out a multiple case study, it was decided to analyze the business model of Alkondor Hengelo, which focuses on the Skin layer, but base its analysis on desk research by examining the company's website, their partner's websites, reports, presentations and interviews of the company regarding facades as a service.

Table 3. 8 Case studies for the purpose of this thesis

COMPANY	DETAILS	LAYER
Mitsubishi Elevators Europe	• Elevators as a service	• Services
Alkondor Hengelo B.V.	• Façades as a service	• Skin

iii. Design of the Data Collection Protocol

According to Bouwman (2018) the following topics should be included in the data collection protocol in brief:

- The sub research question which will be answered: "How have suppliers in the Dutch built environment successfully established product-service systems as circular business models for products, components, and materials in the building layers?"
- The final number of the cases: Two case studies were conducted, namely (1) Mitsubishi Elevators Europe and (2) Alkondor Hengelo
- The data collection procedures: Face to face interviews and desk research
- The case study interviews objective: The analysis of building product, components and material suppliers who have successfully established the PSS CBM in the Dutch built environment.
- The questionnaire: An interview questionnaire (APPENDIX N) was developed in accordance to the case study framework.
- The place and time of the interviews: For the purpose of this thesis the place and time of the interviews will not be revealed for privacy reasons.

The case study framework utilized can be found in Figure x The case study framework presents all the relevant characteristics that can be used for the design of product-service systems as circular business

models; however, it is not expected that the business model analyzed will have all of them. It will be used to check which characteristics have been applied from the under investigation companies and how they have been realized.

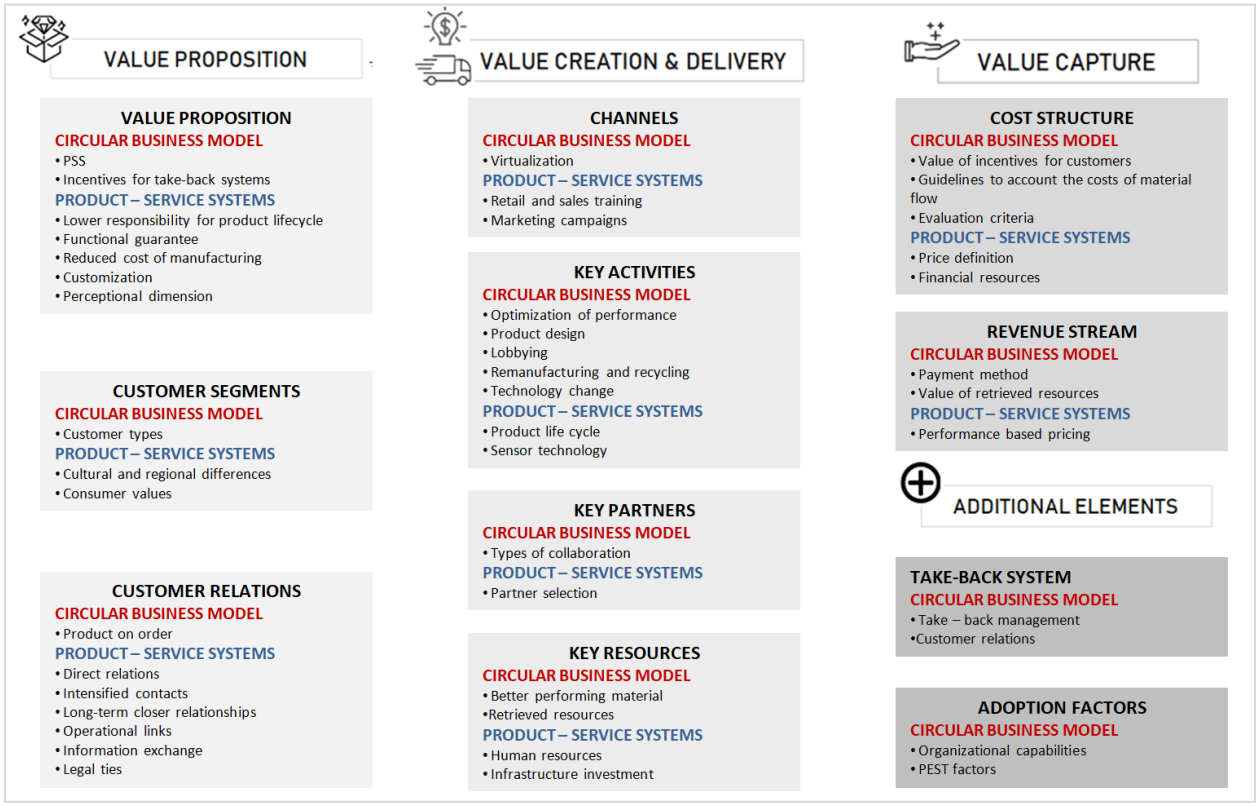

Figure 3. 1 Case study framework
Source: (Lewandowski, 2016; Barquet et al., 2013)

In order to formulate the case study framework a number of business model frameworks were studied and presented in chapter 2.7 for both circular business models and product-service systems. This is because, as pointed out from the literature review, product service systems may be considered as a circular business model type; however, PSSs are not circular unless intentionally designed. This lead the researcher to seek for business model frameworks which clearly present the characteristics required establishing product-service systems and circular business models. As illustrated in chapter 2.7 the business model frameworks for circular business models and product-service systems were analyzed. Antikainen & Valkokari (2016) developed Sustainable Circular Business Model Innovation added on the business model canvas three additional elements, namely (1) Trend and drivers recognition at the ecosystem level (2) Understanding value to partners and stakeholders within a business, (3) Sustainability and circularity impact evaluation. However, this framework was selected, since Bocken et al. (2019), who conducted a review and evaluation of circular business model innovation tools stated that the framework requires further development and refinement. In addition, the circularity characteristics were not clearly presented. What is more, Nussholz (2017) who developed the Circular Business Model framework based on the business model canvas designed to recognize the specific opportunity points on the product lifecycle to create and capture additional value from cycling resources. Nonetheless, this framework was

not chosen since it does not present the circularity characteristics required to guide the design of each business model element.

As a result, Lewandowski (2016) and Barquet et al. (2013) were selected, since their combination will enable the identification of the characteristics required for the design of each business model element both in accordance to servitization and to circularity principles. The two frameworks business model elements are presented and analyzed in APPENDIX O. A number of modifications were done in order to integrate both frameworks in one. Specifically, Lewandowski (2016) recognized in the value proposition element two approached towards ownership, namely: (1) circular products, were considered the ones which were ownership-based, and (2) PSS were the company retains the ownership. Since, the focus of this research is on PSS, circular products were removed from the value proposition element. Additionally, the virtual services characteristic of CBMs which was suggested by Lewandowski (2016) as part of the value proposition element was eliminated, since it does not apply in the built environment. In addition, as concerns customization it was addressed by both Lewandowski (2016) and Barquet et al. (2013) but in different business model elements; the first one referred to it in the value proposition element; whereas, the latter one referred to it on the customer relations one. In the case study framework of this thesis it will be included in the value proposition since customizing product characteristics but most importantly services is a significant aspect of the PSS. What is more, both frameworks base the payment methods on PSS theory; thus, three different ones are presented: (1) availability, (2) usage and (3) performance based. Lewandowski (2016) refers also to a fourth one, namely input-based which is based on paying per product, but since the business models studied are not product-oriented ones it I unlikely for the companies under investigation to apply this payment method. Moreover, additional characteristics which were referred in both Lewandowski's (2016) and Barquet et al. (2013) were considered only ones, such as the adaptation of financial/accounting functions characteristic of PSS was described in the evaluation criteria characteristic of CBM and the social marketing strategies of PSS were studied in virtualization of communication in CBM etc. Finally, some characteristics which did not apply in the cases investigated, or were not identified in the information collected for both cases were not included in the case study framework.

- ***STEP 2:*** *Prepare, Collect, & Analyze*

In this phase of the survey each case was executed for the collection of the relevant data. Since for one of the cases a semi-structured interview was conducted the permission of the participant was asked for recording and transcribing the interview for ethical as well as legal reasons. Afterwards, the cases were analyzed and the results were associated to the conceptual framework. This step enabled the researcher to get an overview of the variables involved in the research and how they are connected. Additionally, this phase provided a first impression of the case study findings.

- ***STEP 3:*** *Analyze & Conclude*

This phase included the analysis of the case study's results and reaching the case study conclusions. A significant part of this phase was the execution of the cross-case analysis, which is generally utilized for the analysis of two or more case studies in order to reach a synthesized outcome. For its successful implementation it involves a variety of tools, such as tables and graphs, for the management and

presentation of qualitative data (Cruzes et al., 2015). Following these guidelines, similarities and differences between the cases were noted, and conclusions were drawn.

3.4 RESEARCH ETHICS

Both the expert consultation and the cases study survey were conducted based on semi-structured interviews. In order to exchange knowledge and information interaction is required between the interviewer and the participants. This comes with a number of responsibilities for the researcher. For the purpose of this research, first both the mental and physical protection of the interviewees was ensured. Moreover, when it comes to the data gathering process and analysis certain guidelines were followed. Specifically, in the initiation of the process the purpose of the interview was explained, and room was left in case further information or clarifications were needed. Furthermore, the permission to record the interview and utilize quotes from the transcripts was asked. In addition, the names of the participants were not revealed for privacy reasons.

CHAPTER 4: RESULTS OF THE EXPERT INTERVIEWS

4.1 INTRODUCTION

In this chapter the findings of the expert interviews are presented and analyzed. The chapter includes information regarding the suppliers' view the application of product-service systems as circular business models in the Dutch built environment. In addition, the implementation of the PSS CBM in the Structure, Skin, and Services layers is examined. Specifically, the barriers of implementing this innovative business model for each of these three layers are discussed, as well as the enablers to overcome them. In addition, the opportunities of its implementation for both the company and the client are analyzed. Finally, barriers and enablers which were pointed out by the experts as relevant to the application of product-service systems as circular business models for the built environment but were not linked to a specific layer are also investigated.

4.2 SUPPLIER'S VIEW ON PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS

One of the objectives of the research interviews was to explore the expert views on the supplier's view on the application of product-service systems for the building's products, components, and materials in the Dutch built environment. The PSS is according to academic and grey literature a promising CBM moving towards the circular built environment. However, its application depends on whether suppliers consider it valuable or interesting for their business; therefore, it is important to understand how they view it. The answers provided by the interviewees pointed out three different views, namely positive (2 out of 10), negative (4 out of 10), and some consider it interesting in specific cases (4 out of 10). Some of the main points made regarding how suppliers view the application of product-service systems as circular business models are summarized in Table 4.1.

Table 4. 1 Supplier's view on product-service systems as circular business model

VIEW	EXPLANATION	MAIN POINTS
Positive	Suppliers consider the PSS CBM as a valuable and/or interesting model for their business	• Fear of missing out
Negative	Suppliers consider the PSS CBM as a valuable and/or interesting model for their business	• Selling the product generates profit in the short term • Business as usual is still profitable • Lack of awareness regarding the opportunities offered • Conservative sector
Depends	Suppliers consider the PSS CBM as a valuable and/or interesting model in specific cases	• Technology embedded i.e. highly technological products • Type of company i.e. start-ups

4.3 PRODUCT SERVICE SYSTEM AS CIRCULAR BUSINESS MODEL: STRUCTURE, SKIN & SERVICES

One of the aims of this research was to investigate whether the application of product-service systems as a circular business model is possible for the different layers of the building. The focus was mainly on the Structure, Skin, and Services Layers.

- **For the Structure layer:**

9 out of 13 experts consider its implementation interesting if certain conditions are met, whereas 4 out of 13 experts believe that it cannot be applied or it is not interesting for this layer.

- **For the Skin layer:**

All 9 who provided an answer agreed that its application interesting.

- **For the Services layer:**

All 12 experts who provided an answer agreed that its application is interesting.

4.4 PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS FOR THE STRUCTURE LAYER

4.4.1 BARRIERS

At this point it is important to look deeper into the reasons which prevent the application of product-service systems as circular business models for the products, components and materials of the structure layer. According to the interview results, 11 out of 13 interviewees pointed out specific barriers regarding the business model's implementation for the building's structure. Figure 4.1 presents the barriers regarding the application of the PSS CBM for the Structure layer and the percentage of experts stating them. The barriers were categorized according to the categories identified in chapter 2.6.1; however, three additional ones were included, namely (1) Products, Components & Materials of the Layer, (2) Part of the Structure, and (3) Lack of Maintenance & Performance Services. Table 4.2 provides an overview of the barriers related to the structure layer. In APPENDIX P examples of quotes from the expert interviews which were used are presented.

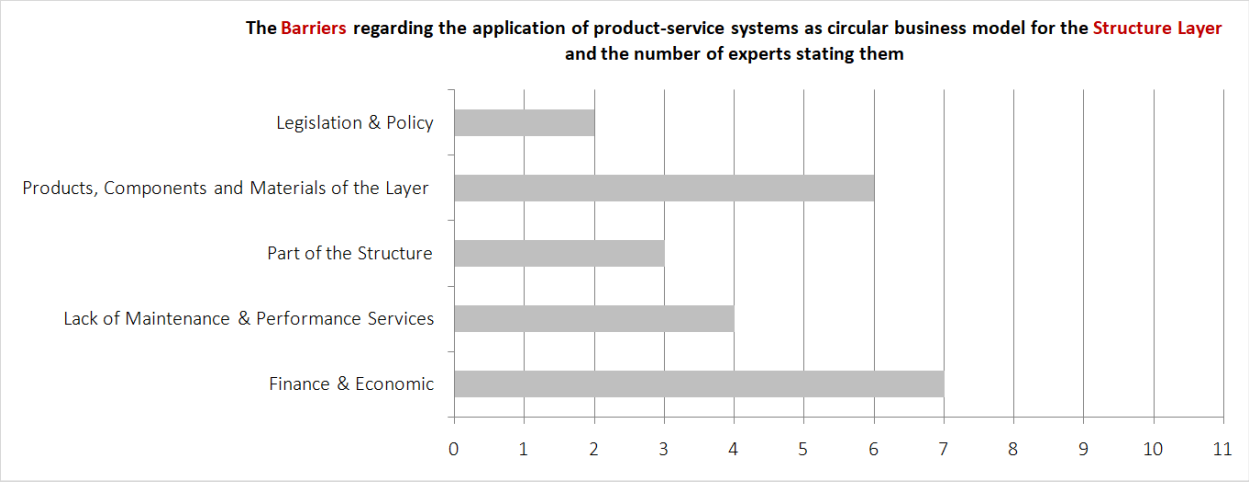

Figure 4. 1 Barriers regarding the application of PSS as a CBM for the Structure Layer

- ***FINANCE & ECONOMIC***

As can be observed in Figure 4.1 financial issues are the ones which were stated by most experts as hindering the application of product-service systems as circular business models in the Structure layer. All experts agreed that one of the main reasons contributing to financial barriers is the layers long lifespan. The application of PSS requires companies to operate with a significantly lower cash flow as a result of the long return on investment period. This means that suppliers need financial institutions to provide financing. However, experts point out that the structure layer's long lifespan creates uncertainty about the future and renders risk assessments difficult; thus, financiers are not in favor of providing financial support.

An additional financial barrier recognized, is the lack of valuation methods for products, components, and materials at the EoL. For products in the circular economy to be reused it is important to know their value

in economic terms in order to allow its resell and reuse. Since, circular economy is in its infancy in the built environment the mechanisms to calculate these values are not yet developed.

- ***THE PRODUCTS, COMPONENTS, AND MATERIALS INVOLVED IN THE LAYER***

All building layers involve different products, components and materials. As concerns the structure it includes elements, such as concrete, steel and bricks. In this context, 6 out of 11 experts recognized that the PCMs may determine whether the application of the PSS CBM is interesting. Specifically, an expert mentioned that reusability of PCMs is a defining factor for the implementation of the PSS CBM; this means that materials which are not easily reusable after the end of the lease period or EoL may not be suitable for the implementation of PSS CBM. The same expert pointed out that in this case concrete may not be suitable for servicing since it is not easily reusable. Furthermore, another expert indicated that product-service systems may not be interesting for low-tech materials, such as concrete. One reason is because high-tech materials, meaning the ones that are more technically complex, will require maintenance service; thus are more appropriate for servitization. Furthermore, an expert focused on concrete structures and pointed out that a number of clients are anxious with the idea of it remaining on their own balance sheet.

As concerns structural steel, a number of experts focused on the difficulties and risks associated with its reuse. In this context, some of them pointed out their concerns regarding its quality and the lack of methods which can guarantee it to be safe and reliable for load bearing purposes. This is especially true in case more than one reused beam is utilized in the same building project. In addition, it was pointed out that currently quality checks are cost intensive; thus, recycling or even manufacturing new ones may prove to be more cost-effective. What is more, an expert indicated that in case the quality of reused steel beams cannot be assured then investors may be reluctant to provide financing.

- ***LACK OF MAINTENANCE AND PERFORMANCE SERVICES***

As can be seen in Figure 4.1, 4 out of 11 experts recognize as a barrier the lack of maintenance and performance services provision for the PCMs in the structure layer. Maintenance is important for product service systems since it is one of the core activities outsourced by the client during the use phase of the building. However, as indicated by experts, updating and changing the structure layer's element is less required, less frequent, and more difficult compared to other layers i.e. services, stuff. These aspects render the implementation of product-service systems as circular business models for this level of the building less interesting.

- ***PART OF THE STRUCTURE***

The structure of the building can be divided in two main parts, the structure above ground and below ground, namely the foundation. One of the findings of the research is that experts consider the foundation, as being the most unsuitable part of the structure to be serviced. This is because it has an even longer lifespan, which makes the implementation of product-service systems as circular business models even more challenging than the above ground structure. In addition, an expert indicates that the foundation is more economically important for financiers and banks; thus, its ownership is important to them.

- ***LEGISLATION & POLICY***

Another main barrier which hampers the application of product-service systems as circular business model is the Dutch property law, as highlighted by 2 out of 11 experts. Specifically, according to the Dutch property law a building's structure belongs to the site, it is called property, and it is considered an immovable good. As a result, the law does not allow someone else being responsible for the structure, because it is related to the building's site. The issue arising is that in product-service systems the responsibility and property rights are kept by the supplier; however, this new ownership model cannot be supported by the current law.

Table 4. 2 Overview of barriers related to the Structure layer

CATEGORY OF BARRIER	EXPLANATION
Finance & Economic	• The structure layer's long lifespan creates uncertainty about the future and renders risk assessments difficult; thus, financiers are not in favor of financing it. • Lack of valuation methods for products, components, and materials at the EoL.
PCMs of the Layer	• Concrete is not easily reusable • Application may not be interesting for low tech material i.e. concrete • Companies do not want the concrete structure on their own balance sheet; thus, they are unwilling to keep its ownership • Lack of methods which can guarantee reused steel to be safe and reliable for load bearing purposes • Reused steel structure quality check are cost intensive
Lack of Maintenance & Performance Services	• Updating and changing the structure layer's element is less required, less frequent, and more difficult compared to other layers
Part of the Structure	• Application for the foundation of the building is less interesting than the above ground structure
Legislation & Policy	• Dutch property law

4.4.2 ENABLERS

At this point it is important to examine how the application of PSS CBM for the PCMs of the structure layer can be facilitated. According to the interview results, 9 out of 13 interviewees pointed out specific enablers regarding business model's implementation for the building's structure. Figure 4.2 presents the enablers for the application of the PSS CBM for the structure layer and the number of experts stating them. The enablers were grouped according to the categories identified in chapter 2.6.1; however, three additional ones were included, namely (1) Products, Components & Materials of the Layer, (2) Part of the Structure, and (3) Lack of Maintenance & Performance Services. Table 4.3 provides an overview of the enablers related to the structure layer. In APPENDIX Q examples of quotes from the expert interviews which were used are presented.

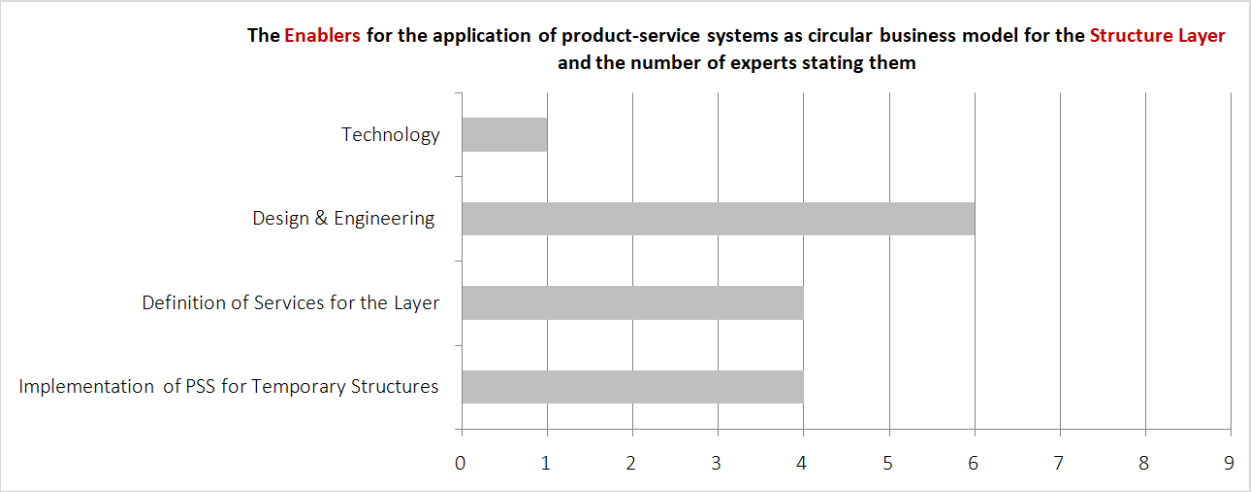

Figure 4. 2 Enablers for the application of PSS as a CBM for the Structure Layer

- ***DESIGN & ENGINEERING***

The main enabler for the application of the product-service systems as circular business model for the structure layer is associated to the products, components and materials design. One of the experts believes that for the business model's application the interaction of three different factors, namely the design, the material used, and the part of the structure should be examined. Two experts agreed that it is important to design the structure's elements for dismantling while taking into consideration minimizing the damage caused to both the product and the environment. Another expert mentioned that the utilization of high value material works as an enabler. To clarify this point the expert focused on steel and mentioned that the material's worth increases with the passage of time; therefore, investing in it and reclaiming it after a long period of time is an important investment opportunity which may motivate producers keeping its ownership. Moreover, experts viewed as an enabler the utilization of materials which are more technically complex, since this allows producers having a knowledge advantage regarding the product's technology and better maintenance provision. What is more, the standardization of PCMs was indicated as an enabler for this building layer, since it facilitates reuse. Based on this argument an expert mentioned that the application of PSS CBM may be easier for steel elements, since they are more standardized. Finally, in order to enable the implementation of PSS CBM for the foundation, an expert suggested engineering a platform that has additional stability.

- ***IMPLEMENTATION OF PSS FOR TEMPORARY STRUCTURES***

In addition, 4 out of 9 experts pointed out that one of the enablers for the application of the product-service system as circular business model is the reduction of the structure's lifespan. As pointed out by an expert, the shorter lifetime facilitates the reuse and/or the exchange of products, components and materials. However, circularity and sustainability support product's life extension and not reduction; thus, in order to align with this principle while facilitating the reuse, the implementation of the PSS for the layer's PCMs is suggested when the building has been decided from the outset that it will be used for a short period of time. For instance, experts suggested the application of PSS CBM for temporary buildings or pop up parking lots.

- ***DEFINITION OF SERVICES FOR THE LAYER***

As aforementioned, the provision of services, such as maintenance and performance ones are important factors for the application of PSS CBM. In this context, 4 out of 9 experts mentioned the importance of defining what services can be provided for the structure layer. Furthermore, two experts pointed out that it would be even more advantageous to combine the provision of a performance model in the case of temporary buildings, since the shorter lifespan enables reclaiming materials which coupled with the provision and optimization of performance, would potentially lead to the reduction of waste generation.

- ***TECHNOLOGY***

An expert due to the difficulty of quality certification of steel beams indicated the need for the development of new technologies. Specifically, the expert proposed the development of components 4D model that keeps track of the materials used, the embedded technology, and the received service life. In this context, the expert mentions that in the case of steel beams the implementation of sensor technology may be required in order to monitor the loads they have received to prove their structural reliability for reuse. However, the expert noted that this huge display of technology might be incredibly expensive and therefore may ruin the business case of the PSS CBM.

Table 4. 3 Overview of the enablers related to the Structure layer

CATEGORY OF ENABLER	EXPLANATION
Design & Engineering	• Examination of the interaction between design, material, and part of the structure. • Design for dismantling while considering minimizing the damage caused to both the product and the environment. • Utilization of high value material • Utilization of PCMs which are technically complex • Standardization of PCMs • Foundation can be serviced if designed as a platform with additional stability
Implementation of PSS for Temporary Structures	• Application of the PSS CBM for temporary buildings
Definition of Services for the Layer	• Defining what services can be provided for the structure layer • Combination of a performance model in the case of a temporary building
Technology	• 4D models of components to keep track of materials the embedded technology, and the received service life • Sensor technology to monitor the loads received

4.5 PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS FOR THE SKIN LAYER

4.5.1 BARRIERS

At this point it is important to look deeper into the reasons which hinder the application of the PSS CBM for the PCMs of the skin layer. Specifically, only one out of the nine experts who expressed their view on the application of the PSS CBM for the skin layer did not indicate specific barriers regarding its implementation. The barriers which were identified are shown in Figure 4.3 and analyzed in following section. Table 4.4 provides an overview of the enablers related to the skin layer. In APPENDIX R examples of quotes from the expert interviews which were used are presented.

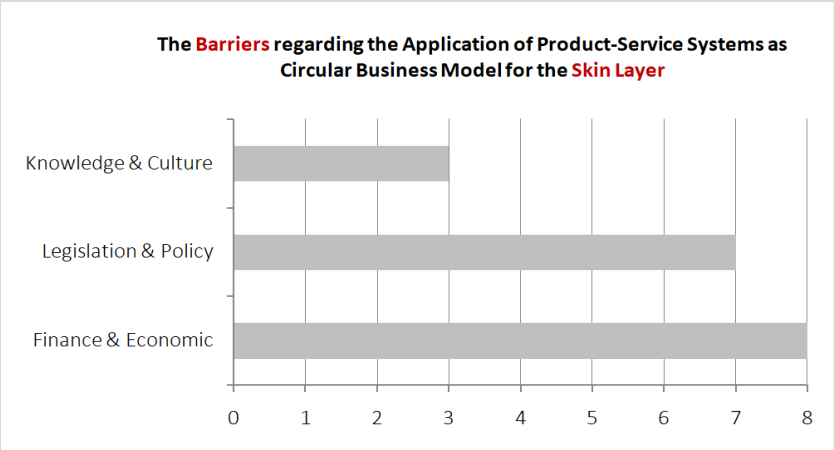

Figure 4. 3 Barriers regarding the application of PSS as a CBM for the Skin Layer

- ***FINANCE & ECONOMIC***

The main barriers hindering the application of product-service systems as circular business models are financial. The implementation of the PSS CBM significantly changes the company's cash-flow, since the company receives the money over the months or years. At the same time companies' have to make a high initial upfront investment in order to pre-finance the façades components. The first issue arising is that since for the realization of a façade a number of parties are involved the question of who will pre-finance the components is raised. In addition, the experts support that façade suppliers are not companies built to make high upfront investments.

In addition, the financing issue is enhanced by the fact that banks are both not used to the building way of thinking and also have a false perception of financing the PSS CBM, since they consider it as another mortgage. Meanwhile, financing from banks is based on risk ratings; however, the lack of track record for façade leasing renders the associated risks very high, thus locking accessibility to funding. In addition, the high investment risk results from the fact that the long lifespan creates uncertainty regarding the company's existence. What is more, two experts pointed out a significant financial question regarding the PSS CBM for the skin layer, namely how much extra it is going to cost because of all the risk premiums. They explained that due to the layer's long lifespan the client has to pay for a number of risks, which in the long term make the service solution more expensive compared to the purchasing one, and stated that in case nothing happens to the façade, all the money spent during these years for risks may not have been worth it at the end.

In addition, another barriers pointed out by two experts is the difficulty convincing organizations for financing. The choices are two; either approaching universities and governments or commercial parties. The first ones seem ideal, because they have a very long term planning; however, due to the fact that these institutions have low credit the financial argument is less attractive to them, since leasing will have higher financial costs compared to purchasing it with money that can be borrowed at low credit ratings. On the other hand, commercial parties will be attracted by the financial argument since this solution will

allow them to save money upfront and invest it in another project; however, in this case they may not be attracted because of the credit costs applied by the bank to make the initial upfront investment.

- ***POLICY & LEGISLATION***

Seven out of eight experts mentioned that the application of this business model is hindered by legal or policy implications. In this context, the Dutch property law was pointed out as a major barrier. The implementation of the PSS CBM means that the ownership remains with the supplier. However, the property law supports that to retain the value of a property it has to be maintained in a fully functional shape and that's more likely to be guaranteed if all of its components are owned by the same party; thus, everything that is fixed to the building becomes property of the building owner. This is related to the fact that companies in the construction sector bankruptcy often get bankrupt. As a result, there is great uncertainty whether the company that is responsible for the façades components and to whom the client has paid the premiums will actually be available after a 15 or 20 years.

Another main barrier which results from the current Dutch regulations is the current taxing system in the Netherlands. Specifically, an expert pointed out that the current labor tax is very high when the building's façade system requires high labor intensity. The same expert mentioned that issues also arise due to the value added tax, and noted that in CE the product will be the same for multiple cycles; thus, charging value added taxes in each cycle is irrational. In addition, another expert focused on the Bouwbesluit, and stated that at the EoL if a producer decided to reuse the façade then it wouldn't match the Bouwbesluit norm anymore.

- ***KNOWLEDGE & CULTURE***

Three out of eight experts indicated that there are a number of barriers associated with the lack of knowledge and culture. Experts pointed out that the façade industry is fragmented; this means that a large number of parties is required for the realization of a façade system each performing a different task. This fact raises issues regarding which party keeps the ownership and the responsibility of the façade and also creates information asymmetry, since different tasks are operated by different actors in the value chain not every party is equally knowledgeable about i.e. materials and processes used which may comprise the circular potential. Furthermore, a major barrier recognized is the lack of information regarding the amount of money spent from real estate managers for managing façades. As a result, there are no tools to balance the new proposal against the current one, since the presented solution is more expensive and its values will be realized in the long term. In addition, it was noted that banks lack knowledge and understanding regarding the PSS CBM application.

Additionally, an interviewee focused on the fact that the application of the business model for the skin layer is constrained by the client's linear way of thinking. In this context, the expert notes that even when a solution has great reuse potential clients decide based on the most economical option. For instance, the expert pointed out that aluminum profiles are recycled, whereas steel profiles can be reused; however, clients go for the cheaper option, namely the aluminum, even though its circular potential is lower due to the recycling. Another main barrier according to the expert is that the steel business in particular and the construction industry as a whole is very conservative; thus, a number of the expert's business partners lack interest and awareness regarding CE creating operational barriers.

Table 4. 4 Overview of the barriers related to the Skin layer

CATEGORY OF BARRIER	EXPLANATION
Finance & Economic	• Cash-flow problem • Difficulty defining which party pre-finances the facades components • Façade suppliers cannot make high upfront investments • Financial institutions are reluctant financing the PSS CBM • High investment risk because of lack of track record for façade leasing • High investment risk because of the long lease period • Service solution is more expensive in the long term compared to purchasing one because of risk premiums • Difficulty convincing organizations for financing
Legislation & Policy	• Dutch property law • Taxing system • Bouwbesluit
Knowledge & Culture	• Fragmented nature of the industry raises issues regarding which party keeps ownership of the façade and creates information asymmetry. • Lack of information to balance servicing to the purchasing option • Customers' linear way of thinking • Steel business in particular and the construction industry as a whole is very conservative

4.5.2 ENABLERS

At this point it is important to examine how the application of PSS CBM for the PCMs of the skin layer can be facilitated. According to the interview results, 9 out of 13 interviewees pointed out specific enablers regarding business model's implementation for the building's skin. Figure 4.4 presents the enablers for the application of the PSS CBM for the skin layer and the number of experts stating them. The enablers were grouped according to the categories identified in chapter 2.6.1; however, an additional one was included, namely (1) Definition of Service and Performance Element for the Layer. Table 4.5 provides an overview of the enablers related to the skin layer In APPENDIX S examples of quotes from the expert interviews which were used are presented.

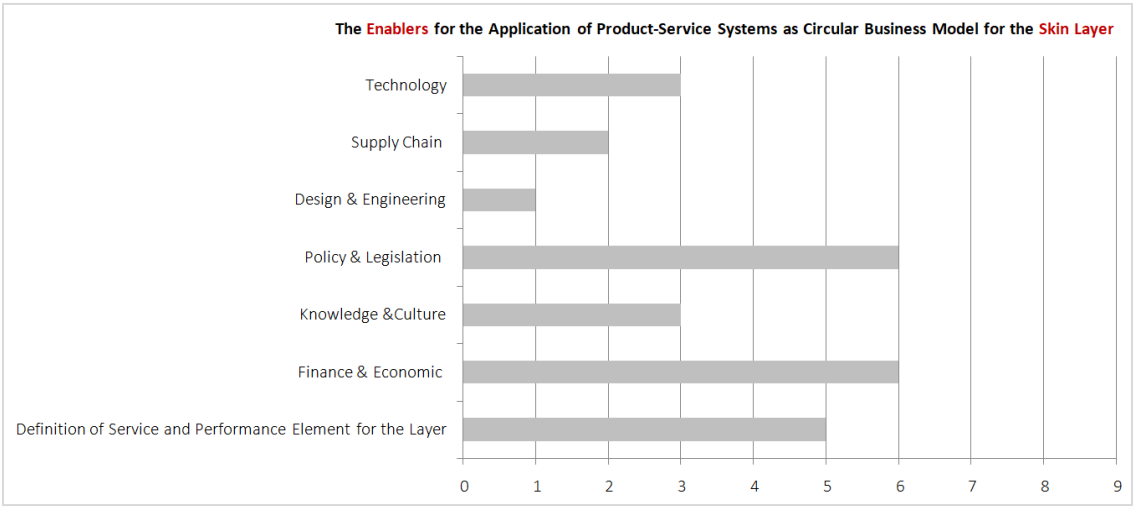

Figure 4. 4 The Enablers for the application of PSS as a CBM for the Skin Layer

- ***DEFINITION OF SERVICE & PERFORMANCE ELEMENT***

As can be observed in Figure 4.4, 5 out of 9 experts pointed out as an enabler the definition of the service and performance component. Specifically, experts agreed that an enabler is the definition of key performance indicators on goals for functionality, such as the delivery of indoor comfort, by designing high quality façades with technology. An expert pointed out that it is important to define what services can be delivered for the skin layer.

- ***FINANCE & ECONOMIC***

6 out of 9 experts pointed out enablers concerned with finance and economic. Specifically, a number of experts agreed that a facilitator for the application of the PSS CBM is finding the right investors. Specifically, an expert mentioned that it is important to identify investors who have a long term vision, due to the façade's long lifespan, and seek for high value property, which will remain on the highest level of quality and will allow them to get their returns in the long term. Two additional aspects were recognized as important for financing the PSS CBM for the skin layer, namely the development of valuation mechanisms and the development of guarantees. Regarding the first aspect developing valuation mechanisms would allow the estimation of the façade's PCMs residual value. In addition, the same expert pointed out as an enabler the development of guarantees, which works as an assurance for the client since they require the service provider to maintain the long-term functionality of the façade. As a facilitator for the provision of guarantees the expert supports the collaboration of producers and investment companies; this way the expert believes that more guarantee can be delivered. Finally, an important enabler to facilitate the application of the PSS CBM for the skin layer of the building it is important to gain information regarding the current expenses of managing façades.

- ***TECHNOLOGY***

An expert indicated that improvements need to be made in terms of live monitoring. In this context, the interviewee suggested the implementation of a building management system connected to the façade's components which would allow producers keep track of the façade's PCMs and gain enough information to commit to a more advanced form of PSS. Furthermore, another expert illustrated the utilization of a harvest map as an enabler, which is a map that indicates which PCMs from a building's façades are available for reuse, and the expert's company is currently experimenting with it small scale. Another expert indicated as an enabler the experimentation with new technologies. First, the interviewee referred to the utilization of a harvest map, which is a digital database where a company can see what material from which building at what point in time will be available for reuse. Secondly, the expert mentioned that exploring ways of integrating new technologies as an important enabler and proposed looking building's façade as a platform where other suppliers can add technologies, such as PV solar panels, and manage it as a kind of platform sharing base. Thirdly, as a way to enhance the circularity of façade's production is 3D printing i.e. for printing the façade's connectors, since this technology allows printing on demand thus reducing waste generation.

- ***POLICY & LEGISLATION***

As indicated by 6 out of 9 experts a number of enablers were identified regarding the current Dutch policy and legislation. In this context, it was mentioned that currently the legal problem of companies

because of the Dutch property law is solved by companies with the development of personalized customized contracts which allow the ownership to be split. However, experts support the need to modify this law in order to facilitate the application of the PSS CBM as a default solution. In this context, an expert stated that the financing and the legal aspect of the PSS CBM are tied together; thus, addressing the legal dimension would facilitate overcoming the financial one. Several experts also agreed on the provision of tax incentives for the application of the PSS CBM. For instance, an expert focused on the need to change the value added tax on PCMs which are sold multiple times. Finally, one interviewee considered lobbying as an important enabler for legislation changes.

- ***KNOWLEDGE & CULTURE***

As indicated by 3 out of 9 experts, ways to increase the knowledge and change the culture were pointed out as possible enablers. In this context, experts pointed out that increasing the awareness of clients by illustrating the opportunities. In this context it was mentioned that it is important to move beyond the ecological argument, and focus on illustrating the opportunities offered by the application of the PSS CBM for the skin layer, such as outsourcing activities like assembly, installation and management. Another expert supported that the client's inclusion in the decision making process, as well as identification of both partners and customers who demand circular solutions work as enablers. Another significant enabler is allowing a good flow of knowledge in companies; thus, the expert suggested inviting students and experts for the evaluation of the current system and identification of possible future improvements which allow the provision of more circular solutions. Experts also illustrated as an enabler the dedication and political willingness of a company to go over the transition period, and step away from business as usual. In this context, an expert suggests that companies should first small scale experiment with product-service systems and CE, while operating in parallel with business as usual.

In addition, as has been aforementioned, a number of parties are involved in the realization of a façade system. In this context, an expert suggested one of the parties becoming responsible for a range of the activities is required with the aim to overcome the interface problems arising from the fragmented nature of the industry. However, for this to be achieved the expert suggested the façade supplier to be initially responsible for specific inter comfort values, and gradually taking more responsibility regarding the building's energy performance. The expert also states that allowing suppliers to have full responsibility of the energy performance works as an incentive engineer the facade as efficient as possible; for instance, companies will replace their current technologies with more energy efficient ones, since making this investment will lead to profit generation in the long term.

- ***DESIGN & ENGINEERING***

Only one expert highlighted the importance of the PCMs design for the implementation of PSS CBM for the skin layer. The expert focused on the façade system and on the importance of designing it in accordance to circularity principles, such as modular design of the system's connections by making them mechanical instead of welding. The interviewee further noted that collaboration with architects who have the knowledge and skills to design in accordance to reversible design principles is very important, since this will enable the easy disassembly of the façade's components. In addition, design for durability was indicated as an important enabler since it allows the design of high quality products and facilitates reuse.

In addition, taking into consideration the EoL when designing for façade leasing was pointed out as an enabler. For this, architects and circular deconstruction companies need to be included from an early phase of the project. Finally, the expert suggested designing the façade for multiple lifecycles i.e. for 10 cycles of 10 years instead of 100 years.

- ***SUPPLY CHAIN***

Three out of nine experts indicated specific enablers regarding the supply chain in order to facilitate the application of the PSS CBM for the skin layer. Experts pointed out the important of collaboration, trust, and knowledge sharing among all supply chain partners who are responsible for bringing facades to life, from designers and builders, to demolishers and developers. In addition, an expert mentioned the need to experiment with the circular network with the aim to establish reverse logistics, since this would allow take back and reuse of the skin layer's PCMs. In addition, an expert considered having an overstock of material important for the application of the PSS CBM for the façade system.

Table 4. 5 Overview of the enablers related to the Skin layer

CATEGORY OF ENABLER	EXPLANATION
Definition of Services & Performance for the Layer	• Definition of key performance indicators on goals for functionality i.e. delivery of indoor comfort • Definition of what services can be provided in the skin layer
Finance & Economic	• Identification of investors with a long term vision seeking high value property • Development of PCMs valuation mechanisms • Development of guarantees • Gain information regarding current expenses for managing facades
Technology	• Improvement in live monitoring technologies • Implementation of building management system • Utilization of harvest map • Explore new ways of technology integration i.e. PV solar panels • 3D printing for reduction of waste generation
Policy & Legislation	• Modification of Dutch property law • Tax incentives • Lobbying
Knowledge & Culture	• Increase the awareness of clients by highlighting the opportunities • Inclusion of clients in decision making process • Identification of partners and clients who demand circular solutions • Dedication and political willingness of a company to go over the transition period • Small scale experimentation with PSS and CE, while parallel doing linear business • One party becoming responsible for a range of activities; however this needs to be done in two phases: (i) Initial phase – Supplier not fully responsible for the energy performance to go through transition period (ii) Second phase – Supplier becomes responsible of energy performance
Design & Engineering	• Modular design • Reversible design principles • Design for durability • Consideration of EoL at an initial phase of the project • Design for multiple lifecycles
Supply Chain	• Trust among the supply chain partners • Collaboration among the supply chain partners

- Knowledge sharing among the supply chain partners
- Experimentation with the circular network to establish reverse logistics
- Overstock of material

4.6 PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS FOR THE SERVICES LAYER

4.6.1 BARRIERS

At this point it is important to look deeper into the reasons which hinder the application of the PSS CBM for the PCMs of the services layer. Only 4 experts pointed out specific barriers regarding PSS CBM for the services layer. The barriers which were identified are shown in Figure 4.5 and analyzed in following section. Table 4.6 provides an overview of the barriers related to the services layer In APPENDIX T examples of quotes from the expert interviews which were used are presented.

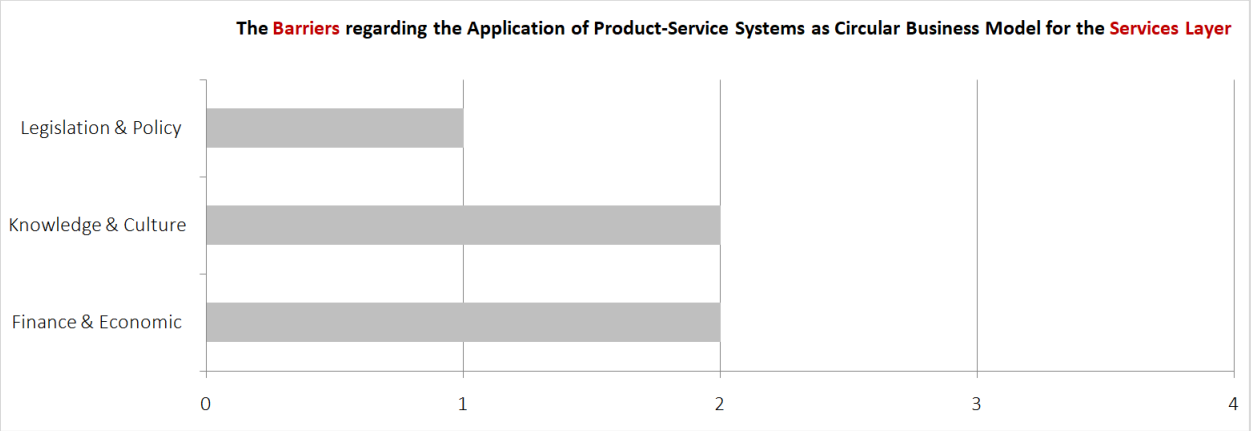

Figure 4. 5 The Barriers regarding the application of PSS as a CBM for the Services Layer

- ***KNOWLEDGE & CULTURE***

Two out four experts indicated specific barriers regarding the lack of knowledge and culture hindering the application of PSS CBM for the services. In this context experts point out that suppliers are very traditional compared to other parties in the building sector; thus, even though they are aware of the business model they are not yet willing to make the transition. In addition, the lack of information regarding the maintenance expenses is an important barrier. Specifically, the lack of tools to compare the servicing solution to the traditional one hinders the uptake of the PSSs as CBMs for the services layer.

- ***LEGISLATION & POLICY***

One expert only focused on the barriers regarding the legislation and policy. Specifically, the expert mentioned that the Dutch property law is hindering the business model's application and provides the example elevators as a service for which the ownership of a part of the building was redefined.

- ***FINANCE & ECONOMIC***

According to the research findings another issue which is hindering the application is financing. Both experts see this issue as a result of the layer's long lifespan.

Table 4. 6 Overview of the barriers related to the Services layer

CATEGORY OF BARRIER	EXPLANATION
Knowledge & Culture	• Suppliers are very traditional • Lack of information regarding maintenance expenses
Legislation & Policy	• Dutch property law
Finance & Economic	• Financing issues mainly because of the layer's long lifespan

4.6.2 ENABLERS

At this point it is important to examine how the application of PSS CBM for the PCMs of the services layer can be facilitated. According to the interview results, 9 out of 13 interviewees pointed out specific enablers regarding business model's implementation for the building's services. Figure 4.6 presents the enablers for the application of the PSS CBM for the skin layer and the number of experts stating them. Table 4.7 provides an overview of the enablers related to the services layer In APPENDIX U examples of quotes from the expert interviews which were used are presented.

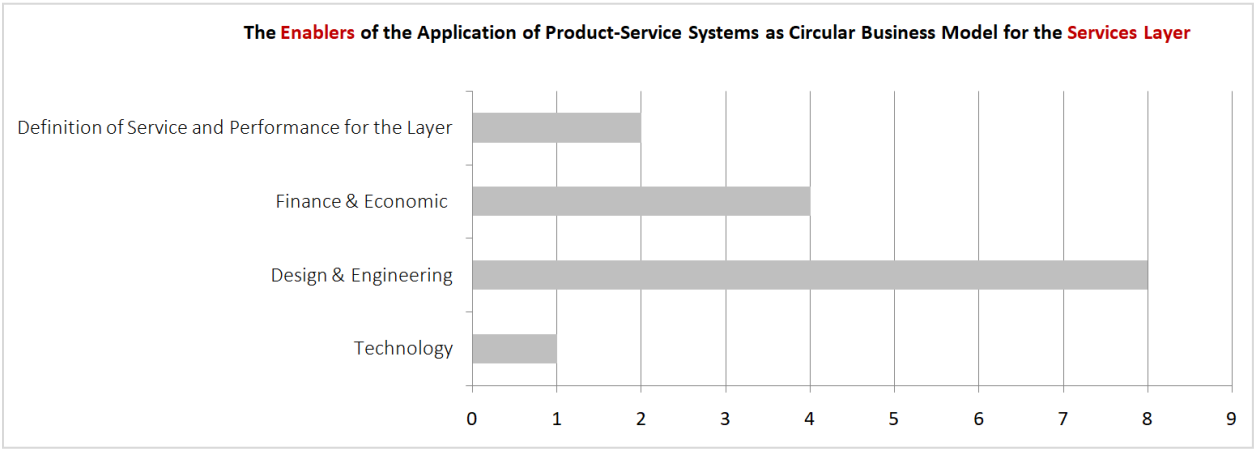

Figure 4. 6 The Enablers for the application of PSS as a CBM for the Services Layer

- ***TECHNOLOGY***

According to one out of nine experts in order to facilitate the application of the PSS CBM for the services layer technological developments are required. Specifically, the expert mentioned the importance of applying sensors and information systems, since these technologies allow monitoring the layer's PCMs and identifying when maintenance or repair is required.

- ***DESIGN & ENGINEERING***

According to eight out of nine experts the PCMs design is an important enabler for the business model's application. In this context, three experts recognized that the application of PSS CBM becomes interesting when technology is embedded on the layer's PCMs. In addition, experts identified the need to take into account the EoL in the design phase as an enabler, in order to allow the PCMs reuse. Moreover, experts considered designing the PCMs of the system low key and easily reachable as a facilitator, since this eases the provision of maintenance services. In addition, another expert mentions that products and

components of the service layer should be designed according to modularization to enable the easy disassembly of systems. What is more, an expert pointed out the need to utilize reusable material.

- ***FINANCE & ECONOMIC***

Three experts indicated the importance of financing as an enabler for the business model's application. In addition, two experts highlighted the optimization of the total cost of ownership as an enabler for the PSS CBM.

- ***DEFINITION OF SERVICE AND PERFORMANCE FOR THE LAYER***

Two out of nine experts pointed out the importance of coupling the PSS CBM for the services layer with a usage model.

Table 4. 7 Overview of the e enablers related to the Services layer

CATEGORY OF ENABLER	EXPLANATION
Technology	• Sensor technology • Information systems
Design & Engineering	• Application of PSS CBM when technology is embedded in the layer's PCMs • Consideration of EoL in the design phase • Design PCMs low key and easily reachable • Modular design • Utilization of reusable material
Finance & Economic	• Optimization of the Total Cost of Ownership
Definition of Service & Performance for the Layer	• Coupling PSS CBM with a usage model

4.7 OPPORTUNITIES OF PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODEL

During the interviews the experts were asked to mention which are according to them the benefits offered by the application of products-service systems as circular business models for the building's PCMs in the Dutch built environment. After their identification the benefits were divided in two main categories; the ones offered to the company and the ones offered to the client. This categorization was based on the literature review (chapter 2.6.2), and both are presented and analyzed in the following section.

4.7.1 OPPORTUNITIES FOR THE COMPANY

The expert interviews revealed 23 opportunities offered by the application of products-service systems as circular business models to the company. After their identification the benefits were grouped in six main categories as presented and explained in Table 4.8. The opportunities for the company were further coded to provide a better structure to the results.

Table 4. 8 Explanation of categorization regarding opportunities offered to the company

CATEGORY	EXPLANATION
Policy & legislation	The opportunity to comply with current regulations and policies
Environment	The positive impact on the environment

Design	The opportunity of the company to improve the design of its products
Technology	The benefits resulting from the application of technologies required for the application of PSSs as CBM
Finance & Economic	The financial and economic benefits
Supply Chain	The benefits related to the supply chain management

All of the results can be found in the APPENDIX V. The most commonly stated opportunities will be analyzed, specifically the benefits which were pointed out by more than 5 experts.

As indicated by the experts the most stated opportunity is managing the PCMs during their lifecycle, since this offers producers a bigger economical and technical incentive to deal with them efficiently during their service life. The economical aspect was linked to the optimization of the total cost of ownership; however, in order to achieve this technical innovation is required. To illustrate this point an expert mentioned that having the responsibility of the PCMs management incentivizes producers to make design decisions which will lower maintenance needs and reduce the associated costs. Another opportunity is that the PSS CBM incentivizes quality, and it is closely linked to the aforementioned benefit. Experts specifically mentioned that it incentivizes quality, since producers optimize products in such a way that all the maintenance and other related activities are lowest and achieve a long product life. Another major opportunity is the access to data. The implementation of the PSS CBM requires suppliers to install new mechanisms which offer the opportunity to learn more about how the product is used. This is important, because it allows them to supply with this kind of new insight a better position to deliver quality to their clients. Other important ones were the generation of higher profit, not in the short term but in the long term; the reduced environmental impact, if designed and managed in accordance to CE principles, as well as the incentive to innovate which is linked to the access to data and the fact that producers are responsible for the PCMs during their lifecycle.

4.7.2 OPPORTUNITIES FOR THE CLIENT

The expert interviews revealed 9 opportunities offered by the application of products-service systems as circular business models to the client (Figure 4.7). In the following section, the most commonly stated opportunities will be analyzed, and specifically the benefits which were pointed out by more than 5 experts.

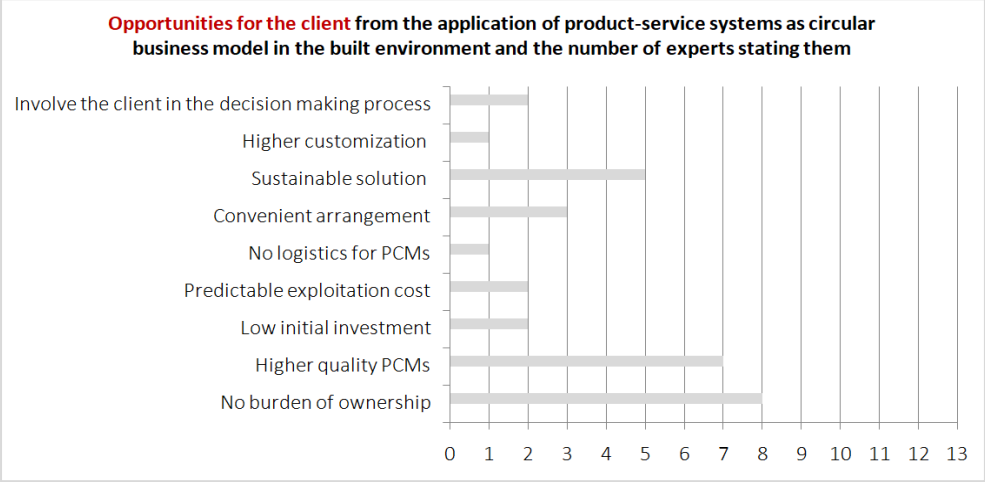

Figure 4. 7 Opportunities offered to the client

The lack of burden of ownership was mainly mentioned as an opportunity for the client. Specifically, experts indicated that the client benefits from outsourcing all activities related to the arrangement and management of PCMs. This is especially true for highly technological products, since in the built environment the owner or user is often a corporate place or investment company, which lacks the required information and knowledge to make the right management decisions. Another opportunity pointed out is that the client has the opportunity to use or have access to high quality products, suppliers have a strong motive to built products which are more durable, aesthetically better, and easily maintained products All these aspects which are the result of the application of the PSS CBM from suppliers when combined increase the overall quality of the PCMs; thus the customer enjoys a better end product. Finally, 5 out of 13 experts pointed out that the client has the opportunity of leveraging the benefits of a sustainable solution.

4.8 BARRIERS OF PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS

In addition to the specific barriers identified for each layer separately, all experts pointed out general barriers hampering the application of product-service systems as circular business models for the product, components and materials of the building. Specifically, from the expert interviews 40 barriers were recognized regarding the implementation of this business model for the building's PCMs in the Dutch built environment. After their identification the challenges were grouped in 6 main categories identified in chapter 2.6.1 to offer a clearer view and better structure to the research findings. All of the barriers identified can be found in APPENDIX W.

- ***FINANCE & ECONOMIC***

Important barriers in this context are the high initial upfront investment, since the companies need to pre-finance their product; the cash flow issue, which significantly changes since companies receive money from their clients every month/year, and the lack of financing, due to financial institutions reluctance to provide financial support because of high risks and their conservative nature. An additional barrier supported by a number of experts was the high cost of transition, since companies would need to greatly invest in infrastructure to support the implementation of the PSS CBM. Moreover, the lack of valuation methods for reused PCMs and the lack of developed market places for secondary PCMs were pointed out as hindering the application of CE thinking in the built environment. Finally, the lack of proof of concept through the communication of cases of companies which have applied the PSS CBM for building's PCMs to highlight the viability of the business case. Finally, an issue recognized was that CE is used as a marketing tool; this is an issue since companies promote circularity without really thinking through how to apply CE principles for product's lifecycle.

- ***DESIGN***

A barrier recognized in this context is the uncertainty of the PCMs quality. This is because testing the safety of PCMs for reuse is currently under experimentation, and a number of factors need to be taken into consideration, such as according to the component how much testing does it require or how difficult is its reuse. The second issue is designing PCMs for EoL; according to the experts the challenge in this case

lies in the fact that the EoL is many years ahead from now which makes it difficult to imagine what has to be built in the present for something that lies far in the future.

- ***SUPPLY CHAIN***

The logistics were the most commonly stated barrier regarding the supply chain aspect of the application of the PSS CBM for the building's PCMs in the Dutch built environment. This is because the implementation of this business model changes both forward and reverse logistics.

- ***KNOWLEDGE & CULTURE***

First of all, experts referred the ownership instead of usership mentality, which is a significant barrier since the application of PSS CBM by definition requires viewing ownership and property differently. In addition, the lack of awareness and interest both in shifting towards CE in the Dutch built environment and in experimenting with innovative business models such as the PSS CBM were mentioned. Moreover, experts supported that companies are unwilling to go through the long transition period due to the mentality that everything needs to be arranged now; whereas, the shift towards the CE paradigm will take time and the benefits will be realized in the long term. Another main barrier is the fact that the Dutch built environment is operating in a linear economy. This is because actors of the Dutch built environment, such as project developers and real estate owners still base their decision on risks, money and time which are the defining factors for business decision making in the linear system. In this context, experts pointed out the fact that there is still an uneven playing field in which linear companies do business and make profit while their adverse environmental impact is not taken into account. As a result, the fact that the linear alternative is still profitable does not motivate companies to make the shift and transition towards CE and business models like the PSS CBM.

- ***POLICY & LEGISLATION***

As concerns the barriers related to policy and legislation, the Dutch property law was noted. According to the legislation, the responsibility of PCMs in the services, skin and structure layer cannot stay with a party that is not related to the building's site. This challenge is the result of the ownership not shifting to the building owner but staying with the supplier of the PCMs. Another barrier was the Bouwbesluit, whose standards do not align with CE and servitization principles. Finally, experts indicated the inadequate policy support as a barrier hindering the application of the PSS CBM in the Dutch built environment.

4.9 ENABLERS OF PRODUCT-SERVICE SYSTEMS AS CIRCULAR BUSINESS MODELS

In addition to the specific enabler identified for each layer separately, all experts pointed out general enablers which could facilitate the application of product-service systems as circular business models for the product, components and materials of the building. Specifically, from the expert interviews 64 enablers were recognized for the implementation of this business model for the building's PCMs in the Dutch built environment. After their identification the challenges were grouped in 6 main categories identified in chapter 2.6.1 to offer a clearer view and better structure to the research findings. All of the enablers identified can be found in APPENDIX X.

- ***POLICY & LEGISLATION***

Changing the Bouwbesluit was indicated as a solution by the experts. Specifically, experts mentioned that it needs to change to include more circularity in it to force the markets to work differently. In addition, changing the Dutch property law was supported by the experts since it will facilitate the PSS CBM to become a default solution in the Dutch built environment. However, until the necessary changes are applied a way to enable the application of product-service systems as circular business model is by developing personalized customized contracts that allow the ownership to be split. In addition, experts suggested that in order to overcome the difficult contracting for PSSs as CBMs a solution could be the development of model or fixed contracts. In this context, an interviewee when asked regarding fixed or model contract also agreed that this could indeed be a possible solution to accelerate the PSS CBM's adoption; however, specified that an issue in this case would be for instance that since building characteristic is different therefore different contract details will be required. In addition, another enabler which was highlighted is the provision of tax incentives. Specifically, in order to move the market towards CE and the PSS a possible solution would be to increase the taxes of raw materials and decrease the ones of labor. Moreover, experts suggested the revision of value added taxes for PCMs with multiple lifecycles. Finally, provision of subsidize from the government to facilitate the initiation and execution of test cases as well as policy support by moving away the focus from recycling towards higher levels of circularity were suggested.

- ***KNOWLEDGE & CULTURE***

The political willingness of stakeholders to take a step away from the transactions of business as usual, and dedicate the time and energy to make the extra investment necessary to go through the transition period. Finally, increasing the knowledge, the awareness and interest were pointed out as enablers, through workshops, events, and seminars.

- ***TECHNOLOGY***

An additional finding of the research is that experts consider an enabler the PCMs to be characterized by complexity and technology. This means that for suppliers of low tech PCMs the application of product-service systems as circular business models will not be interesting, whereas for suppliers of technological products it will be more. The experts argued that this is because suppliers of high tech products have a knowledge advantage which allows them to provide best the related services like maintenance, repair, and update compared to other companies. At the same time the client does not have the responsibility to manage these highly technological products. Additionally, the utilization of material passports was indicated as enablers. Specifically, an expert mentioned that this technology has various benefits to offer to the producer since it allows gaining information and keeping track of the PCMs in the different layers of the building. It is important to note that on the other hand an interviewee even though supported that material passports are important for CE in the built environment, mentioned that for the PSS CBM they would not be required but would be like an add on.

- ***DESIGN***

One important enabler is design in modules or modular design, which would allows taking parts out and reusing them in other buildings; thus increasing the PCMs value over a longer time span. Another

enabling condition recognized the experts was the design in such a way which would allow the parts or components to be easily accessible for maintenance and for the provision of other services.

- ***SUPPLY CHAIN***

As concerns the supply chain aspect related to the application of product-service systems as circular business models an enabler was pointed out by experts is demanding circular solutions from partners; for instance, developers could require from their suppliers to change their design and materials to become more circular.

- ***FINANCE & ECONOMIC***

One of the most important enablers was engineering a competitive business model. In this context, an expert mentioned that since actors in the Dutch built environment still make decisions based on risk, money and time it is suggested for the initial phase of CBM's to develop them in such a way to compete with the linear alternatives. Furthermore, it is important to develop valuation methods for PCMs at the EoL since the information and data provided would be valuable for possible investors. Additionally, to increase the possibility of receiving financing an expert suggested the investment in a combination of layers and combination of types of contracts to make a fundable structure, which would reduce the investment risk.

4.10 CONCLUSIONS

One of the findings of the expert interviews was the identification of the supplier's view regarding the application of product-service systems in the Dutch built environment. The analysis illustrated that this business model may be considered valuable mainly for startup companies and for suppliers of products that have technology embedded. This may be because startups are companies which are more likely to experiment with an innovative business model. As concerns producers of technological products applying the PSS CBM for PCMs may bring a lot of value because there's this information asymmetry by which the supplier has the knowledge about the technology; thus, the company is best capable of managing the products during and after their lifetime. In general, only two experts supported that suppliers view the application of this business model as interesting or valuable. This fact highlights the PSS CBM is not yet accepted as a mainstream business model in the Dutch built environment.

Following this the application of product-service systems as circular business models was examined for the structure, skin, and services layers separately, and it can be concluded that the PSS as CBM is interesting for all three layers; however, as concerns the structure experts noted that it is valuable under conditions. These results can be explained by the fact that research and application of the business model for the structure layer is in its infancy; whereas on the skin and services layer there have been small or big scale projects for experimenting with PSS CBM, which have proved that the business model's application for these levels of the building is interesting and valuable.

As concerns the structure layer, there are still a number of things which need to be considered in order to apply the PSS CBM. The foundation of the structure was pointed out by the experts as difficult to be

serviced. Moreover, as concerns the PCMs involved in this layer; on the one hand, servicing concrete components was considered uninteresting from a number of experts; on the other steel structures, some experts see it as interesting mainly because its standardized or because its value in the long term will be high; however, the methods to guarantee their quality for load bearing purposes are underdeveloped. Additionally, due to the lack of experimentation with this layer experts pointed out the need to define what services or how can a performance model be applied in this case. Furthermore, financial and economical barriers mainly regarding the difficulty of financing the PSS CBM for PCMs with such a long period of time, as well as the lack of valuation methods were pointed out. Enablers were considered the utilization of high value material, designing differently i.e. standardization and design for dismantle, applying novel technologies, and considering the application of the PSS CBM for the services layer only when the building has been decided from the outset to be utilized for a short period of time i.e. temporary buildings.

As concerns the skin layer, more information was provided by the experts mainly because there is a lot of experimentation in this area and because approximately a great percentage of the experts had been involved in projects concerning facades as a service. Most of the experts focused on policy and legislation as well as finance and economics barriers. Interestingly barriers for this layer were identified also regarding knowledge and culture and focused on the fragmented and conservative nature of the industry or industry partners. The enablers identified mainly focused on ways to facilitate financing and overcoming the political and legislative barriers by changing, for instance, the Dutch property law. However, more enablers were pointed out in areas like technology with the implementation of novel technologies, the supply chain by collaborating, trusting and sharing the knowledge among supply chain partners, as well as designing differently, and increasing the knowledge and changing the culture. Finally, defining what services and how a performance model can be delivered were considered significant enablers for the façade as a service. Importance was also given to the fact that companies need to start first small scale with the application of PSS and CE principles while working in parallel with linear business, and gradually make the shift.

As concerns the services layer, the information gathered regarding the barriers is limited and from a small number of experts regarding the application of PSS CBM were gathered. This may be because the business model has already been applied in numerous cases for this layer; thus, the barriers have been already identified. Another reason explaining this may be the shorter lifespan of the products involved in the layer, which renders the application of the business model easier. However, financial and policy barriers were identified again, the first one focusing on the lack of financing and the latter one on the Dutch property law. Barriers also concerning knowledge and culture were pointed out. Furthermore, the enablers indicated are more improvements rather than conditions for the application of the PSS CBM.

Next the opportunities offered by the application of product-service systems as a circular business model in the Dutch built environment were identified. They were divided in two main groups; namely the ones offered to the company and the ones offered to the client. In this context, managing the PCMs during their lifecycle, reduced environmental impact, incentivize quality, access to data, generation of higher profit, and incentive to innovate were the main ones for the company. The ones which were mainly

stated as opportunities for the client were the lack of burden of ownership, the access to high quality products, and the benefit of supporting a sustainable solution, which are closely connected to the first three offered to the company.

CHAPTER 5: RESULTS OF THE CASE STUDY

5.1 INTRODUCTION

This chapter focuses on presenting and analyzing the findings from the case study survey. Two case studies were conducted; the first one examines the business model of Mitsubishi Elevator Europe, which has applied the product as a service as a circular business model for the M-Use elevators, thus the focus is on the Services Layers of the building. The second one examines the business model of Alkondor Hengelo which has applied the product as a service as a circular business model for façade systems, thus the focus is on the Skin Layer of the building. For each case study, a short introduction to the company is made and the company's business model is analyzed according to the Case Study Framework (chapter 3.2.2). Finally, a cross-case analysis is executed in order to investigate the differences and similarities between the PSS CBMs of the two case studies.

5.2 MITSUBISHI ELEVATORS EUROPE

5.2.1 INTRODUCTION

The first company which was chosen for the case study survey is Mitsubishi Elevator Europe, which is the authority in the BeNeLux for the manufacturing and supply of high–quality elevators and escalators. The company belongs in the Mitsubishi Electric Group, which is part of the Japanese Mitsubishi conglomerate. As concerns the company's vision, their aim is the delivery of both optimal and sustainable vertical mobility, and their strategy is focused on the provision of solutions with the aim to enhance the value through the whole value chain and thus have a contribution towards a greener future.

The company changed their traditional way of doing business back in 2009 and transformed its business model, due to market pressures. Mitsubishi saw a market decline from 3,500 units to 1700 units. The organization is highly quality driven; however, the company's clients were not willing to purchase an elevator due its high initial investment cost. In order to continue competing in the market the company decided to switch towards the PSS and lease elevators. Thus MEE's initial focus was to "survive" in the market; the circular economy and sustainability dimension of their new business model was secondary; nevertheless, at this point the company recognizes the gains offered from including these aspects.

5.2.2 RESULTS

In the following section the business model of Mitsubishi Elevators Europe is analyzed. The results will be presented in four dimensions, namely (1) value proposition, (2) value creation and delivery, (3) value capture, and (4) adoption factors. For each section a table will be presented summarizing the main points in relation to the CBM and PSS characteristics from the case study framework.

- VALUE PROPOSITION

The value proposition dimension involves three business model elements, namely the (1) value proposition, (2) customer segments and (3) customer relations which are described in the following section (Table 5.1)

- *Value Proposition*

The company has applied a result-oriented PSS model in which the company delivers the service of high quality vertical mobility according to the level of use. Furthermore, the company retains the ownership of the elevator and is in charge of manufacturing, delivery, installation, maintenance, repairs, replacements, reporting, advice and lift inspections; thus, the client has low responsibility for the product's lifecycle. In addition, at the end of the lease period or at the EoL the ownership of the elevator shifts to the client. At this point the company has the first right to buy back the elevator's PCMs at the current market price, which is considered a financial incentive offered to the client to enable take-back systems. Moreover, the M-Use comes with a performance-based contract based on specific Key Performance Indicators (KPIs) for functionality. In case these goals are not reached, then the company is contractually obliged to pay fines which are translated into discount on the annual cost. As concerns customization, it is enabled on the service level, since the client is involved in the definition of the optimal solution and design performance for the elevator. This is enabled by traffic calculations through elevator simulations which are carried out by the company in collaboration with the customer. As concerns the product's characteristics i.e. specific buttons, customization is not enabled. Finally, the company considers important building trust-based relationships with their clients and to achieve this they consider transparency and guarantee in the long term important.

- *Customer segments*

Mitsubishi targets developers, building contractors and building owners from the Dutch built environment, which are also the groups in the traditional elevator market. In addition, a particular ownership can be also provided to private persons. The company takes into account regional differences, since it considers important offering the M-Use in countries with a drive for circular business; therefore, even though the M-Use is offered only in the Netherlands in the near future the company aims to implement it in Germany and Belgium. Finally, the company examined the clients' values in order to incorporate them in the M-Use and found the most important being sustainability, reliability, optimal return on investment, a problem free elevator management within a strict budget, and low initial investment.

- *Customer relations*

The M-Use is produced on demand, since the production starts once the customer's order has been received. As concerns the relations with their clients, the introduction of the M-Use demanded a different approach in this area; the client-company relationships are now direct, since the client is involved in the customization of the M-Use and the development of the service, intensified, since there are several contact moments between the client and the company concerning maintenance, performance and contract extension, and long term, due to the long lease period of 20 years that can be extended till 40. Mitsubishi values transparent information exchange regarding the M-Use regarding the elevator's performance and is legally linked with the company since a contract is created.

Table 5. 1 Mitsubishi Elevators Europe value proposition dimension

VALUE PROPOSITION	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Product-Service System	• Result-oriented

Incentives for take-back systems	• Financial incentive
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Lower responsibility for product lifecycle	• Ownership with Mitsubishi Elevators Europe
Functional guarantee	• Contractual agreement based on specific KPIs
Customization	• Possible on the service level
Perceptional dimension	• Trust based relationship ensured with transparency and guarantee
CUSTOMER SEGMENTS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Customer types	• Developers, contractors, building owners, private people
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Cultural and regional differences	• Aiming countries with a drive for circular business
Customers values	• Each customer type's values were recognized
CUSTOMER RELATIONS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Product on order	• Production starts once the customer's order has been received
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Direct relations	• Client involved in customization of the M-USE
Intensified contacts	• Several contact moments for maintenance, performance and contract extension
Long term relationships	• Lease period from 20 years till 40 years
Information exchange	• Transparent information exchange regarding KPIs
Legal ties	• Contractual agreement

- VALUE CREATION & DELIVERY

The value creation and delivery dimension involves three business model elements, namely the (1) channels, (2) key resources, (3) key partners, and (4) key activities which are described in the following section (Table 5.2)

- *Channels*

One of the strongest shifts towards a circular business model regarding channels is virtualization, which is observed in Mitsubishi's business model in offering the M-Use via the company's website. In addition the company is communicating the value proposition through social marketing strategies, by being active on Instagram, LinkedIn, facebook and Twitter, and through websites partners from the Dutch built environment. As concerns Mitsubishi's marketing strategies, they focus on the benefits of the service-oriented business model, which are the high quality vertical mobility, the delivery of a sustainable and circular solution, offered with a low initial investment, and the value of outsourcing services.

- *Key resources*

Mitsubishi has not changed the materials used for the engineering of the elevators; however, the company aims to change them in the future. Moreover, the company has not yet utilized secondary material for the manufacturing of the M-Use. As has been aforementioned, the company designs the elevators to enable reuse of PCMs in other locations; however, it has not yet been applied yet. This is because they are operating only 3 years with this business model, when the initial lease period is 20 years and can be extended till 40. Furthermore, Mitsubishi had to radically change the company's human resources i.e. sales people were trained and new ones were recruited to support the service-oriented business. As concerns infrastructure investment, the company's factory and head office are ISO 14001: 2015 certified, which is a sign that Mitsubishi is moving towards a direction of preventing environmental damage and improved environmental performance.

- *Key partners*

The establishment of a PSS CBM requires the identification of actors and of the competencies they can provide. Mitsubishi performs the manufacturing, delivery, installation and maintenance without external partners. The company chooses this because it allows the easy arrangement of the M-Use. As has been aforementioned, one of the main challenges the company had to overcome is financing the PSS CBM. For this reason the company has partnered up with ABN AMRO and the bank compensates Mitsubishi for the cost of installation up front. Another main partner is Madaster, which is a platform focused on the valuation of material. Mitsubishi brings the material passports of the elevator's PCMs and Madaster evaluate their residual worth. Moreover, the company works closely with REMONDIS, which is a recycling company. Specifically, Mitsubishi collaborates with this company in order to enhance their circular business; this is because through this partnership the company's elevators are dismantled after their initial technical service life and valuable PCMs, such as parts of circuits, are recycled. Finally, in order to support the transition from the traditional product-oriented business model towards the PSS CBM the company collaborated with the consulting firm KPMG. Therefore, it can be concluded that the company selects its partners according to the company's needs.

- *Key Activities*

Mitsubishi provides customers' an optimized performance by monitoring the elevator's KPIs for noise, vibrations, and disturbances and ensured by the contractual penalties. In addition, design principles which aim to reduce material input for the elevator, and enable easy assembly and disassembly have been applied. They are also aiming in the first quarter of 2020 to introduce elevators based on cradle to cradle philosophy. Regarding lobbying the company does not engage in this activity since they consider the political and legal environment as a difficult and slow to change. As concerns recycling, the company has arranged the lifts in such a way that the lifts after their service life can be disassembled and valuable materials can be recycled, whereas regarding the reuse of products in the elevators Mitsubishi is currently researching and developing how this can be achieved. In addition, through sensor technology the company keeps track of the elevator for product life extension and by using material passports to monitor the elevator's PCMs. In this context, the company aims to continuously change its technology since new technologies create more data and create a better margin on service level agreement in the future. In addition, more information in the material passports, such as labor and energy cost. As concerns the company's involvement in the product's lifecycle, Mitsubishi is active before during and after the use phase. The company is in charge of the manufacturing, delivery, assembly, maintenance, repairing etc.

Table 5. 2 Mitsubishi Elevators Europe value creation and delivery dimension

CHANNELS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Virtualization	• Selling and promoting the M-Use online
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Marketing campaigns	• Focused on the benefits of the service-oriented business model
KEY RESOURCES	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Better performing material	• The company has not changed the materials they were using
Retrieved resources	• The aim is to reuse the PCMs taken – back after the end of lease period

PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Human resources	• Focused on the benefits of the service-oriented business model
Infrastructure investment	• Investment in invest in prevention of environmental damage and improvement of environmental performance
KEY PARTNERS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Types of collaboration	• Financing – ABN AMRO/Bank • Recycling – REMONDIS/ Recycling companies • PCMs valuation – Madaster/ Platform • Consulting – KPMG/Consultancy firm
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Partner selection	• According to competences required and activities to be performed
KEY ACTIVITIES	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Optimization of performance	• Performance optimized through monitoring KPIs and the contract
Product design	• Design for easy assembly and disassembly
Lobbying	• Company does not engage in lobbying activities
Remanufacturing and recycling	• Recycling products, components and materials
Technology change	• Improve sensor technology and material passports
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Product life cycle	• Company is responsible for the activities during the entire lifecycle
Sensor technology	• Implemented sensor technology to keep track of elevators

- VALUE CAPTURE

The value creation and delivery dimension involves two business model elements, namely the (1) cost structure and (2) revenue stream which are described in the following section (Table 5.3)

- *Cost Structure*

In this context it is important to note that MEE has changed the way of calculating the total cost of ownership. Traditionally, the dimensions which were taken into account are energy costs, maintenance and renovation fees, and initial purchase. However, in the new way of calculating the true total cost of usership, the company includes energy costs, lease payments, initial investment (direct costs), as well as socio economic and environmental impacts (external costs). Through the collaboration with Madaster the company has been able to calculate the value of PCMs during lifespan. As concerns incentives provided to the client, if the company does not reach the contractual goals promised to the client, they have to pay penalties translated into discounts on the annual payment. Another incentive provided to the client, is that at the end of the end of the lease period or at the EoL the company has the first right to buy back the elevator's PCMs according to their residual value. Finally, the company receives financing from ABN AMRO; therefore, it has to pay extra costs of financing, which are the charges involved in the borrowing of money

- *Revenue Stream*

The company has observed a positive impact on their revenues because of the introduction of the PSS CBM. The revenue streams are the monthly fees the customers pay based on the level of usage of the elevator. Mitsubishi has a guaranteed income during the duration of the contract. In addition, revenue at the end of the contract can result from the elevator's residual value; this is enabled through the cooperation with Madaster.

Table 5. 3 Mitsubishi Elevators Europe value capture dimension

COST STRUCTURE	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Evaluation criteria	• Include socio economic and environmental impacts
Value of incentives for customers	• Buy back at PCMs at EoL / Penalties if issues arise with the KPIs
Guidelines to account the costs of material flow	• Material passports allows knowing the value of PCMs
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Price definition	• According to competences required and activities to be performed
Financial resources	• Financing received from bank
REVENUE STREAM	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Usage-based revenue	• The company's revenue is calculated based on the use
Value of retrieved resources	• The value is known from the material passports
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Payment based on	• Payment based on the level of usage and is adjusted annually

- ADDITIONAL ELEMENTS

The additional elements dimension involves two business model elements, namely the (1) take-back systems and (2) adoption factors which are described in the following section (Table 5.4).

- *Adoption factors*

Internally the company had to change its capabilities; therefore brought new people in and trained the old ones in order to support the new service-oriented business model. In addition, the organization formed for the same reason new partnerships. The adoption of M-Use has been affected by a number of different external factors. Legally the company is striving to develop contracts for retaining the ownership of the elevators; thus, it can be said that the legislative environment is hindering the implementation of elevators as a service. As concerns social factors, M-Use has been delivered in countries which have a drive for circular business. Economical factors were since the company changed their traditional business model in order to survive in the elevator market, as pointed out in the introduction of the chapter. In addition, technological factors like the advent of sensor technology and material passports have facilitated the adoption of the M-Use.

- *Take-back system*

The company has not yet taken back PCMs from elevators that have been already installed; therefore, numerous aspects of take-back system have not yet been thought of. However, they have adjusted their design in order to facilitate easy dismantle and enable reuse of the PCMs. They have also contractually agreed with their clients that the company has the first right to buy back the PCMs at the EoL. In order to do so, as aforementioned, the company has collaborated with Madaster to calculate the residual value of the PCMs.

Table 5. 4 Mitsubishi Elevators Europe additional element dimension

ADOPTION FACTORS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Organizational capabilities	• Contractual agreement which states the company's first right to buy back the PCMs in their residual value
PEST factors	• Political, Economical, Social, & Technological
TAKE-BACK SYSTEM	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	

Customer relations	• Contractual agreement which states the company's first right to buy back the PCMs
Take-back management	• *This information was not identified*

5.2.3 VALUE CREATION FOR SOCIETY, ENVIRONMENT, AND ECONOMY

Mitsubishi Elevators Europe has adopted a sustainability perspective; thus, value is created for the environment by lowering CO2 emissions through energy use reduction, transportation and maintenance; as well as from the utilization of fewer raw materials compared to linear elevator business models, due to monitoring of maintenance and reuse of components. As concerns the value for society is created though reducing elevator incidents and delays, manufacturing health and safety incidents, and minimizing noise and vibration. Finally, economic value is created by the reduction of operation, energy, incident, & storage costs

5.3 ALKONDOR HENGELO

5.3.1 INTRODUCTION

The second company chosen for the case study survey is Alkondor Hengelo a façade specialist which is in charge of the engineering, development and assembly of façade systems. The company has been experimenting with the PSS CBM since 2016, when the company delivered at the TU Delft campus a pilot project which was focusing on façade leasing. Since then it has continued researching and developing circular façades as a service, with one of the most recent project being the development of Dynamic Facades as a Service.

5.3.2 RESULTS

In the following section the business model of Alkondor Hengelo is analyzed. The results will be presented in four dimensions, namely (1) value proposition, (2) value creation and delivery, (3) value capture, and (4) adoption factors. For each section a table will be presented summarizing the main points in relation to the CBM and PSS characteristics from the case study framework.

- VALUE PROPOSITION

The value proposition dimension involves three business model elements, namely the (1) value proposition, (2) customer segments and (3) customer relations which are described in the following section (Table 5.5).

- *Value Proposition*

Alkondor Hengelo delivers high quality façades as a service. The company retains the ownership of the façade and is in charge of engineering, production, assembly, maintenance, and update. Alkondor has applied the result-oriented PSS model which includes the full management of the façade system based on a performance contract, which is developed for a period, for example of 15 years, and the performance is monitored using specific KPIs (Alkondor, 2019a; Alkondor, 2019c). Specifically, the company offers (Alkondor, 2019a; Alkondor, 2019c): (1) Aesthetic performance, the façade looks at all times aesthetically at a good condition (2) Technical performance, the façade functions at all times as has

been predetermined, in terms of comfort i.e. thermal, sound, air, and light quality, as well as operability of doors and windows, and the façade is water and wind resistant. (3) Flexible performance, the facade is changeable and removable, and (4) Take-back guarantee, which means that at the EoL Alkondor Hengelo takes the façade back in order to reuse or recycle its PCMs. As concerns customization, the company designs together with the client the technical aspects, and focuses on optimization of the user experience, as well as on realizing sustainability goals (Alkondor, 2019a). In addition, the façade is designed to be flexible; therefore, it enables to change in accordance to the requirements and wishes of building users and owners during the façades lifespan (Alkondor, 2019a). The company in order to gain the customer's trust offers a complete management sealed with a performance contracts.

- *Customer segments*

Alkondor Hengelo main customers of the façade as a service are property owners, such as developers and building owners, which are also the customer segment in the traditional façade market (Alkondor, 2019c; TU Delft, 2019). Finally, the company examined the clients' values in order to incorporate them in façade as a service and found the most important being sustainability, circularity low initial investment, and finally the provision of comfort services and energy performance.

- *Customer relations*

Alkondor Hengelo produces façades on order. As concerns the relations with their clients, the introduction of the façades as a service demanded a different approach in this area; the client-company relationships are now direct, since the customer is involved in the design phase, their contacts are intensified, since the company is in charge of the management and maintenance of the façade during its lifecycle, and long term relationships are created, for a lifespan varying from 10 to 15 years (Alkondor, 2019a). Alkondor Hengelo values transparent information exchange regarding the M-Use regarding the elevator's performance and is legally linked with the company since a contract is created.

Table 5. 5 Alkondor Hengelo value proposition dimension

VALUE PROPOSITION	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Product-Service System	• Result-oriented
Incentives for take-back systems	• *This information was not identified*
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Lower responsibility for product lifecycle	• Ownership with Alkondor Hengelo
Functional guarantee	• Contractual agreement based on specific KPIs
Customization	• Possible on both product and service level
Perceptional dimension	• Trust based relationship sealed with guarantee
CUSTOMER SEGMENTS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Customer types	• Developers and building owners
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Cultural and regional differences	• *This information was not identified*
Customers values	• Each customer type's values were recognized
CUSTOMER RELATIONS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Product on order	• Production starts once the customer's order has been received
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	

Direct relations	•	Client involved in customization of the M-USE
Intensified contacts	•	Several contact moments for maintenance, performance and contract extension
Long term relationships	•	Lease period from 10 years to 15 years
Information exchange	•	Transparent information exchange regarding KPIs
Legal ties	•	Contractual agreement

- VALUE CREATION & DELIVERY

The value creation and delivery dimension involves three business model elements, namely the (1) channels, (2) key resources, (3) key partners, and (4) key activities which are described in the following section (Table 5.6)

- *Channels*

As concerns virtualization the company is communicating virtually with the customer, through the company's websites, as well as through social media platforms, like facebook, LinkedIn, and Twitter. In addition, Alkondor Hengelo has strong community partners; thus, the façade as a service has been promoted also through their websites. Their marketing focuses on illustrating the benefits of the service-oriented business model; namely, the high quality product, high level of performance, sustainability, circularity and low total cost of ownership (Oost NL, 2018).

- *Key Resources*

Alkondor Hengelo has not altered the materials used for the façade as a service. The company is producing façades made from aluminum and glass, and Alkondor supports that the material used hasn't changed because both of them are reusable, and in case they can't be reused they can be recycled. Specifically, as concerns aluminium the company mentions that its melting requires only 5% of the initial energy required to extract primary aluminum from the Bauxite raw material.

- *Key Partners*

The establishment of a PSS CBM requires the identification of actors and of the competencies they can provide. Alkondor supports that the realization of the façade system requires a large network which jointly delivers the circular façade (Alkondor, 2019a). As concerns Alkondor Hengelo, the company is part of a collaborative initiative known as the Circular Facade Economy, where all chain partners collaborate in order to achieve the high-quality recycling of facade PCMs (Corporatiebouw, 2018). Another significant partner of the company is the one with the branch organization for façades, namely VMRG. Specifically, this organization facilitated Alkondor develop the leasehold agreement with a law firm which enabled the façade as a service (Alkondor, 2018). Generally, the company collaborates with numerous industry partners according to the different projects it is involved. For instance for the Dynamis Façade as a Service, which required new sensor technology to be applied, new automated windows, and solar panels the company collaborated with companies which could provide these technologies. Finally, the company considers collaborating with numerous industry partners valuable since this leads to new relationships, to new potential customers or partners, and to cross-fertilization (Alkondor, 2019a).

- *Key Activities*

Alkondor Hengelo provides customers' an optimized performance and comfort by monitoring performance KPIs i.e. for wind and waterproof, sun-shading, operability of windows. In addition, Alkondor

designs the façade systems to be flexible, modular and demountable; thus, the PCMs are removable and customizable. Furthermore, the company in order to ensure circularity and servitization follows four circles for the façade system. The first circle is concerned with maintenance and service of the façades PCMs; the second one is concerned with the update of the facades i.e. renewing glass and sun blinds, the third circle stands for the reuse of products, and the fourth and final one stands for recycling aluminium and glass. As concerns the technology utilized, the company collaborates with industry partners to update the technology used varying from drones and sensors, to artificial intelligence with the aim to offer a more efficient maintenance concept for property owners. For instance, the company in collaboration with a number of industry partners has developed the Facade Identification System (FIS), which enables the creation of a 3D representation of a building by the scanning of façade products with a QR code by smartphone.

Table 5. 6 Alkondor Hengelo value proposition dimension

CHANNELS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Virtualization	• Promoting façades
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Marketing campaigns	• Focused on the benefits of the service-oriented business model
KEY RESOURCES	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Better performing material	• The company has not changed the materials they were using
Retrieved resources	• *This information was not identified*
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Human resources	• *This information was not identified*
Infrastructure investment	• *This information was not identified*
KEY PARTNERS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Types of collaboration	• According to competences required and activities to be performed
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Partner selection	• According to competences required and activities to be performed
KEY ACTIVITIES	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Optimization of performance	• Performance optimized through monitoring KPIs and the contract
Product design	• Design for flexibility, modularity, and demountability
Lobbying	• *This information was not identified*
Remanufacturing and recycling	• Four cycles of circularity
Technology change	• Artificial intelligence, sensor technology and drones
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS CHARACTERISTICS	
Product life cycle	• Company is responsible for the activities during the entire lifecycle
Sensor technology	• To keep track of performance and comfort

- VALUE CAPTURE

The value creation and delivery dimension involves two business model elements, namely the (1) cost structure and (2) revenue stream which are described in the following section.

- *Cost Structure*

Alkondor aims at optimizing the Total Cost of Ownership. Information regarding this business model element was not found.

- *Revenue Stream*

Information regarding this business model element was not found.

- ADDITIONAL ELEMENTS

The additional elements dimension involves two business model elements, namely the (1) take-back systems and (2) adoption factors which are described in the following section (Table 5.7)

- *Adoption Factors*

Political factors which are supporting Alkondor Hengelo's façade as a service are the stricter upcoming environmental impact requirements; thus, complying with them will be important for building owners (Corporatiebouw, 2018). Additionally, another political factor contributing to the implementation of the PSS CBM for the facades are subsidize. The company has managed to receive the iPro-N grant which was provided to the company for the research and development of the Dynamic Facades as a Service project (Oost NL, 2018). However, a political factor which was hindering the application of the façade as a service was the Dutch property law. Technological factors are also important since the advent of technology has significantly facilitated the development of facades as a service.

- *Take back systems*

Take back systems for the façades PCMs have been established since the company retains the ownership of the material and aims to reuse or recycle them after the EoL. However, in detail information regarding these systems could not be found

Table 5. 7 Alkondor Hengelo value capture

ADOPTION FACTORS	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Organizational capabilities	• *This information was not identified*
PEST factors	• Political & Technological
TAKE-BACK SYSTEM	
CIRCULAR BUSINESS MODEL CANVAS CHARACTERISTICS	
Customer relations	• Contractual agreement which states the company's first right to buy back the PCMs
Take-back management	• *This information was not identified*

5.3.3 VALUE CREATION FOR SOCIETY, ENVIRONMENT, AND ECONOMY

As has been aforementioned, the company strives for the realization of sustainability goals; in this context, they aim to not only create economic value for the company, but also for the environment and for society. As concerns the environment, Alkondor Hengelo's circular façade enables the maximization of the reusability of the facades' PCMs and reduction of raw material usage (Alkondor, 2018). In addition, the company mentions that one of the main opportunities offered by the façade as a service is that it complies with strict environmental requirements (Corporatiebouw, 2018). As regards society, the client is given the opportunity to have a high performance and comfort without the burden of ownership and with a low initial investment. In addition, the company and all the partners working in

the Façade Service Application (FaSA), consider the application of the PSS CBM as a way to increase affordability of homes due to lower maintenance (Boosting, 2019)

5.4 CROSS – CASE ANALYSIS

The cross case analysis was conducted by comparing how the two companies have applied both circularity and servitization principles for each business model element.

BUSINESS MODEL ELEMENT	SIMILARITIES	DIFFERENCES
VALUE PROPOSITION	• Result-oriented PSS CBMs • Retain the ownership of their product and have the responsibility for the manufacturing, delivery, installation, maintenance, repairs, replacements, reporting, and advice. • Offer high quality products • Offer a contract based on specific KPIs • Have applied take-back systems to enable reuse or recycle of the PCMs • Aim to build up trust with customers and this is translated to the contracts	• Mitsubishi offers customization on the service level, whereas Alkondor offers both on the service level and product level • The KPIs used differ because of the different performance model offered in the different layers.
CUSTOMER RELATIONS	• Have changed the way they approach the company-client relationships and aim to build closer long term relations with their customers. • Have legal ties with the client which is not the norm in the linear business	• The lease period is different; Mitsubishi elevators are offered till 40 years whereas Alkondor's facades from 10 till 15 years. This was unexpected since the Skin layer according to Brand's 6S framework has a longer lifespan compared to the Services one.
CUSTOMER SEGMENTS	• Offer their product to the same client segments as in the linear economy. • Offer low initial investment and sustainability to their customers • Produce on demand	-
CHANNELS	• Promote the PSS CBM by utilizing social media platforms • Marketing strategies focus on promoting the benefits offered from the service-oriented business model	-
KEY RESOURCES	• Have not altered the materials utilized with better performing ones.	• Mitsubishi aims to change the materials utilized for the production of façades in the future; Alkondor aims to continue using aluminum and glass since the company considers these materials ideal
KEY ACTIVITIES	• Aim to optimize the performance through monitoring the relevant KPIs • Design taking into account easy assembly and disassembly	-

	• Aim to reuse and recycle • Utilize new technologies • Implement sensor technology to keep track of their product's PCMs	
KEY PARTNERS	• Collaborate with partners to achieve high quality recycling • Do not collaborate with partners for installation, maintenance, and update.	
COST STRUCTURE	• Optimization of Total Cost of Ownership	-
REVENUE STREAM	-	-
TAKE-BACK SYSTEM	-	
ADOPTION FACTORS	• Political: Difficulty due to current property law • Technological: Both companies have been facilitated by the advent of technology	-

5.5 CONCLUSIONS

The case study's aim was to illustrate how companies active in the built environment have successfully applied product-service systems as circular business models. For this reason the business models of two companies active in two different layers were studied, namely Mitsubishi Elevators Europe which delivers elevators as a service (Services Layer) and Alkondor Hengelo which offers façades as a service (Skin Layer). The findings of the case study illustrated:

- Both companies in order to successfully implement product-service systems as circular business models examined and applied both the characteristics related to circularity and the ones related to servitization when designing all business model elements.

- Even though the companies' focus in different layers of the building the cross case analysis illustrated that the similarities of their business models are more than the differences.

- The analysis of the value proposition element highlighted the importance of offering high quality products, retaining the ownership and having the responsibility of activities during the entire lifecycle of the product, developing a service agreement based on specific KPIs in order to monitor the performance, applying take-back systems to enable reuse and recycle, and building trust based relationship with the customer. On the other hand, one difference because of the companies' focus in different layers are the different KPIs which are utilized for monitoring the performance. In this context, Alkondor Hengelo has the opportunity to extend their service from energy performance to also the provision of comfort services i.e. room temperature, light regulation etc. This is a major opportunity for façades as a service since it enables the provision of higher level product-service systems. Furthermore, the analysis highlighted the significance of customization in the provision of product-service systems and that it may focus more on the service level rather than the product level. This may also be due to the companies' choice, namely for Alkondor it is important to enable

customization whereas for Mitsubishi it may not be. Another explanation would be due to the layer of the building; it can be said that for the skin layer being the outside of the aesthetics of the product play role, whereas in the case of elevators aesthetics may be considered secondary.

- The analysis of the customer segments did not change; however, it was illustrated that it is important to gain deep insight regarding the demands of the clients in order to create the new value proposition.

- The analysis of the customer relations between the company and the client change radically due to servitization; they are intensified, direct, long term and sealed with legal ties.

- The analysis of the channels illustrated the importance of utilizing social media platforms for promoting the new business model, since it allows the company to communicate virtually with the client. Moreover, the channels are significantly altered, since marketing campaigns focus on promoting the services provided rather than the product.

- The analysis of key resources illustrated that companies have not altered the materials utilized for the application of the PSS CBM even though it is an important aspect of CE. As concerns the utilization of retrieved resources the companies have not reused PCMs mainly because products, components and materials have not been taken back due to the long lease period; however, both companies aim to use secondary resources. In addition, the findings highlight that the implementation of PSS CBM require the organization to rethink some internal organizational factors, i.e. rethinking human resources i.e. training and recruiting staff to support circularity and servitization, as well as infrastructure investment to have a better environmental impact.

- The analysis of the key activities illustrated that even though reuse is important for both companies they significantly focus on recycling, which is a low level of circularity, which means that in this context there is still room for improvement. Moreover, the findings illustrate the importance of altering the design approach to enable easy assembly and disassembly. Lobbying for change, even though suggested in order to put pressure on the political environment, seems not to be a priority for the companies. As concerns technology, the findings illustrate that it plays a great role in the successful delivery of the PSS CBM since technologies, like sensor technology enable keeping track of PCMs, calculating the PCMs' residual value, and enable the optimization of maintenance.

- The analysis of the key partners illustrated the importance of collaboration for the implementation of the PSS CBM. Both companies have a strong network of partners; however, the network of Mitsubishi was better depicted and provided important insights. Specifically, the examination of the company's partners showed the enabling role of receiving financing, the importance of monitoring the residual value of PCMs with the implementation of material passports, as well as the importance of consulting firms in making the shift and changing the valuation of the Total Cost of Ownership. In addition, Mitsubishi has a smaller network of partners compared to Alkondors; this may be because the

delivery of elevators requires less actors compared to the delivery of façades, or it may be because it is the choice of Mitsubishi to act independently.

- The analysis of the revenue stream of Mitsubishi showed that even though the company has applied the M-Use only three years it has affected positively the company's profit.

- The analysis of the cost structure, the evaluation criteria of the cost may change to include socio economic and environmental impact. Buy-back incentives are enabled by the application of technologies which allow calculating the residual value of PCMs; however, there are still improvements to be made. As concerns receiving financing to support the new business is important due to the changed cash-flow and the need to pre-finance.

- The analysis of adoption factors showed that political factors like the Dutch property law are indeed hindering the application of the PSS CBM; however, the contracts can be developed to support the split of ownership. As concerns technological factors, the advent of technology has been facilitating the implementation of the service-oriented circular business model.

- The analysis of take-back systems shows that due to the long lease period these systems have not been utilized yet; thus, improvements will be realized with the passage of time.

Both companies have established the product-service system as circular business model; however, both of them are still working on linear projects. This is an important finding since it shows that in order to go through the transition period companies in the built environment should take small steps and experiment with circular business in parallel with business as usual, and make plans on how to proceed in the future.

CHAPTER 6: DISCUSSION

6.1 INTRODUCTION

The aim of this chapter is to reflect on the research process, as well as the research findings and provide a deeper interpretation of their meaning. The chapter first presents the limitations regarding the literature review, the expert interviews, and the case study survey. To continue, the managerial, academic and broader relevance of this thesis is discussed.

6.2 LIMITATIONS

6.2.1 LITERATURE REVIEW LIMITATIONS

The overarching goal of the literature review, presented in chapter 2, was to present a comprehensive review of the relevant and recent academic work on circular economy in the built environment, circular business models and product-service systems, and gain theoretical knowledge which would work as a basis for the research. Even though an extensive literature review was conducted information on concepts may have been missed out. In addition, a limitation of this research is related to the business model frameworks reviewed in chapter 2.7. In the current literature there are numerous scientific papers analyzing PSS and CBM frameworks; however, for the purpose of this research four were chosen to be studied. This means that if different frameworks were selected to be examined and used alternative insights may have been provided. Another limitation of this research was caused due to language restrictions. In addition, the research was concerned with the application of product-service systems as circular business models in the Dutch built environment. Therefore, relevant literature written in Dutch was examined; however, the researcher utilized translation tools which may in some cases mistranslated or misinterpreted parts of the literature.

6.2.2 EXPERT INTERVIEW LIMITATIONS

At this part of the discussion the limitations regarding the expert interviews will be presented and analyzed. First of all, a limitation that can be recognized is related to the interviewed sample. As illustrated in chapter 3, the aim was to conduct interviews with experts from all the roles identified in chapter 2.3.3 since this would enable getting a more complete overview of the subject; however, this aim was not achieved, since for instance developers and contractors were not interviewed. In addition, due to the implementation of the judgment sampling only the experts who were conveniently available were interviewed; thus, the generalizability of the results may be curtailed. Moreover, since all interviewed experts are based in the Netherlands the generalizability of the results for other countries may not be possible or should be done with care.

6.2.3 CASE STUDY SURVEY LIMITATIONS

As concerns the case study survey, a number of different limitations can be recognized. First of all, the choice of case study framework may be considered a limitation, since for the purpose of this thesis four different frameworks have been studied; however, there may have been other frameworks in literature which if studied could have provided different or better insights. Furthermore, another limitation

recognized related to the case study survey is the limited number of case studies conducted. The initial goal was to perform 4 case studies, in order to examine the business model of two companies which are focused on the Skin layer, and two which are focused on the Services layer. However, only two were conducted, one from the Services and one from the Skin layer. An additional limitation in this context was that only one out of the two cases was based on a semi-structured interview, namely the one of Mitsubishi Elevators Europe. The case study which focuses on the analysis of Alkondor Hengelo, was based on articles, the company's and their partner's websites, reports, presentations and interviews of the company regarding façades as a service. The fact that the case was not conducted based on an interview and that the case study analysis has not been reviewed by a person from the company related to façades as a service may be considered a limitation of this study. Finally, both companies are based in the Netherlands; therefore, generalizability of the results for other countries may not be possible or should be done with care.

6.3 SCIENTIFIC CONTRIBUTION

This research is contributing to academia in several ways. To begin with, Adams et al. (2017) supported that the implementation of CE principles in the built environment is in its infancy. In this context, this research contributes scientifically through the thorough examination of circular economy thinking and its application in the built environment. For instance, the current state of circular economy in the Dutch built environment was examined, as well as the lifecycle stages of the buildings in the linear built environment and how they should be approached in the circular one is analyzed in the following sections. In addition, according to scientific literature, circular economy has mainly focused on short and medium lived manufactured products (Pomponi & Moncaster, 2017). The focus of this research was on the buildings' layers which have a long lifespan, namely the Services, Skin and Structure layer; thus adding new insights to literature regarding long-lived products. Furthermore, even though business models which include changing the ownership of buildings' PCMs and servicing these are considered key in shifting towards a circular built environment (Leising et al., 2018) scientific research regarding the application of this type of models in the building sector is limited. This fact was also proved from the literature review conducted (chapter 2) since only two scientific papers were identified which specifically study the implementation of PSS as CBMs in the built environment; namely, Rios & Grau (2019) and Azcarate et al. (2018). Moreover, this research project contributes scientifically through the thorough literature review which examined the theories and definitions of the relevant concepts and the exploratory research which identified the barriers and enablers of the implementation of the PSSs as CBM for the PCMs in the different building layers; thus, providing valuable insights in this emerging research area. Finally, academia calls for more case studies that can prove the business case of circular business models (Hart et al., 2019). In this context, this research contributes through the business model analysis of two case companies which have successfully applied the PSS CBM, namely elevators as a service of Mitsubishi Elevators Europe and façades as a service of Alkondor Hengelo.

6.4 MANAGERIAL RELEVANCE

Besides the scientific contribution, this research also has managerial implications. This research provides valuable insights to companies interested in integrating circular economy thinking in their way of doing business. First of all, it enables organizations active in the built environment, which aim to transform their business model with the incorporation of circularity and servitization principles, gain deep understanding on the barriers as well as the enablers to overcome them. As was explained in chapter 1 of this research the concept of circular economy is proposed to change the current production and consumption patterns. The Dutch government set the tone on a global scale with the publication of the Transition Agenda: Circular Economy in the Netherlands by 2050 with the aim to create a future-proof sustainable economy. One of the first industries to make the shift is construction; therefore, companies in the sector will be required to comply with the new policies and standards by integrating circular economy thinking. In this context, business models are considered one of the building blocks to transition towards circular economy, and especially the ones which allow new ownership relationships. Therefore, this research allows companies which are active in the built environment gain knowledge and insights which may facilitate the transformation of their business model. By examining the different barriers in the different layers of the building organizations may be able to recognize what is hindering the application of product-service systems as circular business models in their own company, and through the examination of enablers understand how to overcome them. Moreover, the developed case study framework may work as a guiding tool for companies to incorporate circularity and servitization in their business model, by looking into the characteristics listed in each business model element.

6.5 BROADER RELEVANCE

This section clarifies the reasons which make this research relevant. The implementation of CE principles in the built environment is not yet accepted. This research is relevant to the shift towards a built environment which supports CE by examining circular business models, and most importantly the ones which enable new ownership models, since these have been suggested as important enablers to make this transition. However, much more is needed for CE to be fully established in the built environment and in general. Change is required in the macro-,meso-, and micro-level in order to overcome the barriers hindering its application. On the micro-level organizations and companies need to start embracing CE principles in the way they operate internally and the way they do business. In the meso-level supply chains operating in the built environment need to create a strong vision regarding the application of CE in the built environment, embrace it and collaborate in order to achieve it. As concerns the macro-level, governments need to create policies supporting the implementation of CE thinking in the sector and change current regulation as they have the power to ensure a level playing field. In this context, recognizing the opportunities, barriers and enabling conditions of the application of the PSS CBM for the PCMs in the building layers is important since it provided insights which are relevant to all three aforementioned levels.

CHAPTER 7: CONCLUSIONS

7.1 CHAPTER INTRODUCTION

The aim of this chapter is to provide the main conclusions of this research. For this reason, first an answer is provided to each sub-research question in order to address the main research question, namely **"What is the current state of product-service systems as circular business models in the built environment and how can its application contribute to a circular built environment?"** Based on the research findings, recommendations are provided to each stakeholder group, as well as suggestions for future research.

7.2 CONCLUSION TO ANSWER MAIN RESEARCH QUESTION

In order to answer the main research question each SRQ identified in chapter 1.5 of this thesis will be addressed. The first sub-research question will be answered based on the literature presented in chapter 2, subsequently the second one will be addressed based on the findings of the expert interviews in chapter 4, whereas the fourth one will be answered taking into account the results of the case study survey presented in chapter 5.

- ***SRQ1:*** *What is the scientific progress on the circular built environment and circular business models and which are the main barriers and enablers?*

The literature review pointed out the importance of CE and its potential to decouple economic growth from resource consumption by closing the resource loops, as well as the need for CE to have a contribution to all three pillars of sustainable development: economy, environment and society. Regarding the built environment its significance was illustrated, since all of its individual elements affect both the built and natural environment, as well as human-environment relationships.

As concerns the Dutch built environment, efforts to incorporate CE thinking in the sector were recognized; however, it was highlighted that CE practices are not yet fully accepted. In addition, the examination of literature regarding the application of CE thinking in the built environment illustrated that the shift towards CE in the sector will be driven by the different stakeholders involved; however, it was observed that actors' decisions are still based on money and risk, whereas sustainability and circularity are secondary. Moreover, the review suggested the urgency to incorporate CE principles in all lifecycle stages of the building and pointed out the design for disassembly principles being critical for closing the loop. In addition, the need to apply ownership models which allow PCMs to be temporarily stored in the building and the importance of Brand's "6S" layers for circular buildings was acknowledged due to its numerous benefits.

The review conducted illustrated that scientific literature is increasingly focusing on circular business models, which is also highlighting the companies' important role in the transition. It was found that circular business models incorporate strategies which aim to close, slow, and narrow resource loops. In this context, product-service systems are considered promising business models for CE with one of the main reasons being that they enable the ownership to be retained by producers. Three types of PSS were indicated based on the ratio of service and ownership, each of them having different CE potential with

the most promising being the result-oriented one. PSSs as CBMs slow resource loops through product life extension, and close resource loops through disassembly and recovery at the EoL. However, PSSs are neither inherently circular nor sustainable unless intentionally designed; for this the LCA was pointed out as an important tool.

The examination of current literature regarding the application of product-service systems as circular business models in the built environment pointed out a number of barriers and enablers resulting from the application of CE thinking in the built environment or the implementation of PSSs as CBMs. Subsequently, it was found that the barriers and enablers are related to six categories, namely (1) knowledge & culture, (2) policy& legislation, (3) finance & economic, (4) supply chain, (5) design, and (6) technology, which highlighted that in order for PSSs to be established as CBMs in the built environment CE thinking needs to be incorporated and changes need to be made in all these fields. The barriers which were mainly mentioned were the lack of knowledge, lack of supporting regulations, the fragmented supply chain, as well as high investment cost, the difficulty of designing for EoL, along with the design complexity, whereas the enablers were the implementation of Internet of Things and the connection of devices, mainly because it allows companies to both collect and transmit data.

- ***SRQ2:*** *What are the opportunities, barriers and enablers regarding the application of product-service systems as circular business models in the Dutch built environment?*

This study aimed to explore the opportunities, barriers and enablers of the application of product service systems as circular business models in the Dutch built environment. The identified opportunities are offered to the company and the client. What can be observed is that the main opportunities offered to the company are closely linked to the ones of the client, since the incentive to produce higher quality products is directly linked to the higher quality of PCMs offered to the client. This can also be observed in the case of managing the PCMs during lifetime, which is an opportunity for the company and it is closely linked to the lack of burden of ownership for the client. Furthermore, another main opportunity offered to the company due to the application of PSSs as CBMs is the higher profit, which can be considered as one of the most important ones since profit making is essential for businesses and this benefit may indeed motivate organizations to implement this business model. In addition, the application of new technologies allows companies accessing data from which innovation is incentivized; thus allowing them with this new insight to provide a better product and a higher level of service. Finally, the reduced environmental impact was recognized as one of the main opportunities and it may also motivate companies to rethink their business model, since improving the environmental performance is becoming an increasingly important target for today's organizations.

As concerns the barriers and enablers they were studied for the three layers separately, namely the structure, skin and services. It can be concluded that the application of PSSs as CBMs for the PCMs in the structure layer is in its infancy and there is still a lot of research necessary to gain deep understanding of how this business model can be applied. Barriers in this layer were mainly financial and economical, and related to the lack of financing due to the lack of valuation methods for PCMs as well as the layer's long lifespan. Moreover, experts pointed out that the PCMs involved in this layer may not be suitable for

servicing, and indicated that the foundation of the structure is less interesting. In addition, there is the need to define what services can be provided in the case of applying PSSs as CBMs. In order to overcome the barriers experts mainly focused on enablers related to the design and engineering of PCMs. It was interesting to see that the utilization of materials which have high value may enable the application of the business model for the structure layer. To clarify this point an expert focused on steel and mentioned that the material's worth increases with the passage of time; therefore, investing in it and reclaiming it after a long period of time is an important investment opportunity which may motivate producers keeping its ownership. In addition, it was suggested for buildings which are temporary, since the long lifespan of the layer is reduced.

As concerns the skin layer, the information gathered was more mainly because there is currently a lot of experimentation and research in this area and a great percentage of the experts interviewed had been involved in projects related to facades as a service. The main barriers were financial and legal; however, in this case experts pointed out issues related to the lack of knowledge and culture, such as the fragmented façade industry and conservative partners. The enablers in this layer mainly focused on finding financial support and solving the political barriers by changing, for instance, the Dutch property law or the current taxation system. However, more enablers were pointed out in areas like technology i.e. by implementing building management systems, supply chain by collaborating with partners and creating trust based relationships, by experimenting with reverse logistics, designing differently in order to enable disassembly and reuse, and increasing the knowledge and changing the culture through increasing the awareness of clients by highlighting the opportunities or by including them in the decision making process. Furthermore, also in this case the definition of what services can be provided as well as the improvement of the performance model delivered were considered significant enablers for the façade as a service. Finally, attention was paid to the fact that companies need to start first small scale with the application of PSS and CE principles while working in parallel with linear business, and gradually make the shift.

As concerns the services layer, when compared to the other layers the information gathered regarding the barriers was limited and from a small number of experts. This may be because the business model has already been applied in numerous cases for this layer and barriers have been already identified and overcome. Another reason explaining this may be the shorter lifespan of the products involved in the layer, which renders the application of the business model easier. However, financial and policy barriers were once again identified, the first one focusing on the lack of financing and the latter one on the Dutch property law. Also in this case, barriers concerning knowledge and culture were pointed out, like the lack of information regarding maintenance expenses and suppliers being very traditional and operating in a linear way. Furthermore, the enablers indicated are more improvements rather than conditions for the application of the PSS CBM.

Overall, the barriers were mainly financial and specifically focused on the financing problem as a result of the long lifespan on the layers. In addition, the Dutch property law was identified as a common barrier. Moreover, in the skin and services layers the conservative nature of the industry was a common issue. Looking into the enablers, the common ones were related to designing in such a way that allows easy maintenance, assembly and disassembly. In addition, the materials and products utilized in the layers are

important and the analysis showed that the ones which are easily reusable, raw material with high value in the long term, and the ones which have technology embedded may be more suitable to be serviced. Moreover, for all three layers building management and information systems play a very important role. Finally, for all three layers defining the services which can be provided or combining a performance model were considered important.

- ***SRQ3:*** *How have suppliers in the Netherlands successfully established product-service systems as circular business models for products, components, and materials in the building layers?*

First of all, one important finding regarding the case study survey is that no company that has applied product-service systems as circular business models for the structure layer was identified, which illustrates that the business model's implementation for this level of the building is still in its infancy. As concerns the case study survey it was indicated that for the successful establishment of product-service systems as circular business model it is necessary to incorporate servitization and circularity principles in all the different elements of the business model.

The value proposition of both companies analyzed focused on the delivery of high quality products, retaining the ownership and having the responsibility of all activities during the lifecycle of the product, developing a service agreement based on KPIs, applying take-back systems, and building trust based relationship with the customer. In addition, customization is enabled in both companies; however, the analysis showed that Mitsubishi allows it only on the service level, whereas Alkondor enables it both for the product and the service, which may be because of companies' different approach or because of the different layers of the building. Moreover, the customer segments change due to the PSS CBM; however, the customer relations significantly did, since they are intensified, direct, long term and sealed with legal ties. In addition, the company's channels focus on virtual communication with the clients and marketing campaigns illustrate the benefits of the service-oriented business model. Regarding the companies' key resources, the materials have not yet changed and the use of retrieved resources has not been realized due to the long lease period. The analysis also pointed out that the companies when reuse is not enabled focus on recycling; however, since it is the final level of circularity there may be room for improvement. In addition, the design and the technological tools utilized were updated in order to keep track of PCMs, calculate their residual value, and enable the optimization of maintenance. As concerns key partners, both companies have a strong network of partners who support their shift towards circularity and servitization. Information regarding the revenue stream were limited but showed that the PSS CBM application has a positive influence on the company's profit. The cost structure significantly changes since the evaluation criteria of the cost may change to include socio economic and environmental impact, and companies may need to pay extra costs of financing. The analysis of adoption factors showed that political factors like the Dutch property law are indeed hindering the application of the PSS CBM; however, the contracts can be developed to support the split of ownership. The analysis of take-back systems shows that due to the long lease period these systems have not been utilized yet; thus, improvements will be realized with the passage of time.

Finally, what was indicated is that both companies are still working on linear projects. This is an important finding since it shows that in order to go through the transition period companies in the built environment should take small steps and experiment with circular business while continuing with business as usual. Overall, the implementation of PSS CBM requires companies to change radically form how they operate internally to how they communicate with and approach both their clients and their partners.

- **MAIN RESEARCH QUESTION:** *"What is the current state of product-service systems as circular business models in the built environment and how can its application contribute to a circular built environment?"*

Product-service systems as circular business models are regarded as pioneering business models to shift the production and consumption from the linear model towards CE in the built environment. Their contribution is based on slowing resource loops through product life extension, and closing resource loops through disassembly, recovery at the end of life, and reuse. Even though the opportunities offered by this business model for the built environment are numerous it is not yet accepted in the building sector and its application is hindered by a number of barriers varying from financial and legal to cultural ones. In order to facilitate its implementation it is important to closely examine the enablers as ways to overcome the identified issues. Furthermore, due to the fact that the PSS is not inherently circular its design should focus on implementing both servitization and circularity principles in all business model elements in order for it to contribute to a circular built environment. What is more, the application of the PSS CBM requires companies in the sector to not only change their way of doing business but also increase their knowledge regarding CE principles. Most importantly though, companies need to come together and collaborate, because change cannot come from a single organization. Finally, due to the fact that the transition period towards both circularity and servitization is complex and challenging businesses need to take small steps, experiment, and invest time and energy in order to have a positive contribution.

7.3 RECOMMENDATIONS

In the following section recommendation for policy makers and for suppliers who wish to apply product-service systems are provided, as well as recommendations for further research. In APPENDIX Y recommendations to each stakeholder actor from the built environment are presented.

7.3.1 RECOMMENDATIONS TO POLICY MAKERS

In this transition the role of policy makers is of high importance. Governments need to create a level playing field and provide fiscal stimulus to companies which are experimenting with circular economy and the application of product-service systems as circular business models. This means the provision of subsidize for innovation and tax incentives, such as changing the value added tax, or increasing raw material tax while decreasing labor tax is suggested. Furthermore, the minimum standards to get a building permission as indicated in the Bouwbesluit should be stricter and should take into account circularity and servitization principles. In addition, the Dutch property law should change for the circular

economy and supports the introduction of product-service systems as circular business models. The tendering process should also require suppliers to meet circularity standards. Finally, workshops and events which inform and educate regarding policies, regulations, and contracting barriers should be organized.

7.3.2 RECOMMENDATIONS TO SERVICE PROVIDERS

The introduction of the PSS CBM is possible by a number of parties, ranging from the suppliers to the manufactures, and from distributors to installation companies. In the linear economy the supply chain is fragmented which causes an interface barrier between the different actors. However, the PSS as a circular business model needs circular supply chains in order to be implemented; thus collaboration is required. In order to support, the introduction of PSS as CBM suppliers and manufacturers of building material should aim to produce high-tech products and components, or aim at using materials with high value. In this context, it is highly recommended to apply design principles in accordance to circularity and servitization. Moreover, it is important to engineer a business model which can compete with the linear alternative and try to incorporate servitization and circularity principles. In this context, the optimization of the total cost of ownership, keeping performance at high level, and ensure a high residual value is important. All this can be achieved with the implementation of the right technology like building information systems (BIM) and material passports. In order to overcome the financial barriers, it is suggested to identify investors with a long term vision who are willing to invest in high quality PCMs, or to collaborate with investors and introduce together product-service systems as circular business models, or by getting access to finance from new companies which focus on providing flexible solutions for investing in the PSS CBM.

7.3.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This research indicated that the PSSs as CBMs can be applied for the PCMs in the Structure, Skin and Services layer of the building. However, further research is required in order for this business model to become mainstream in the Dutch built environment. Findings of this research indicated different categories of barriers for each layer. Further research could therefore focus on one category of barriers and conduct an in-depth investigation to find the root of the problem and how to overcome them. In addition, from the case study interview the participant mentioned that in order to reuse a PCM it is important to calculate the residual value at the EoL or at the end of the contract period, and noted that research should be done to examine how much energy and how much labor is required in order to reuse the PCMs.

Another, important enabler of the PSSs as CBMs is the application of the business model their assessment proposal includes different layers of the building, different PCMs with different values; different technology updates, and PCMs from the different layers of the building. Having a combination of distinct risks from each layer in a fund leads to the reduction of the investment risk; this increases the likelihood of getting access to financing. The in-depth investigation of this enabling condition would be beneficial since it would facilitate the implementation of PSSs as CBMs by overcoming one of the most important barriers, namely the financial one.

In addition, expert interviews with each stakeholder group and most importantly with the suppliers in order to gain deep understanding of their perception, since for this research this was pointed out by different stakeholder groups. In addition, a research which includes more participants and includes all actors from stakeholder groups would provide a better overview of the opportunities, barriers, and enablers. Moreover, identifying the PCMs in the different layers for which PSSs can be applied as CBMs could facilitate the business model's application.

Furthermore, the identification of companies which failed to implement the PSSs as CBMs would be beneficial to examine as part of case study survey since this would allow the identification of the reasons and mistakes which may have led the company to this point. Finally, conducting case studies also with companies which have successfully applied PSSs as CBMs in the built environment is recommended for future research, since this study managed to examine a limited number.

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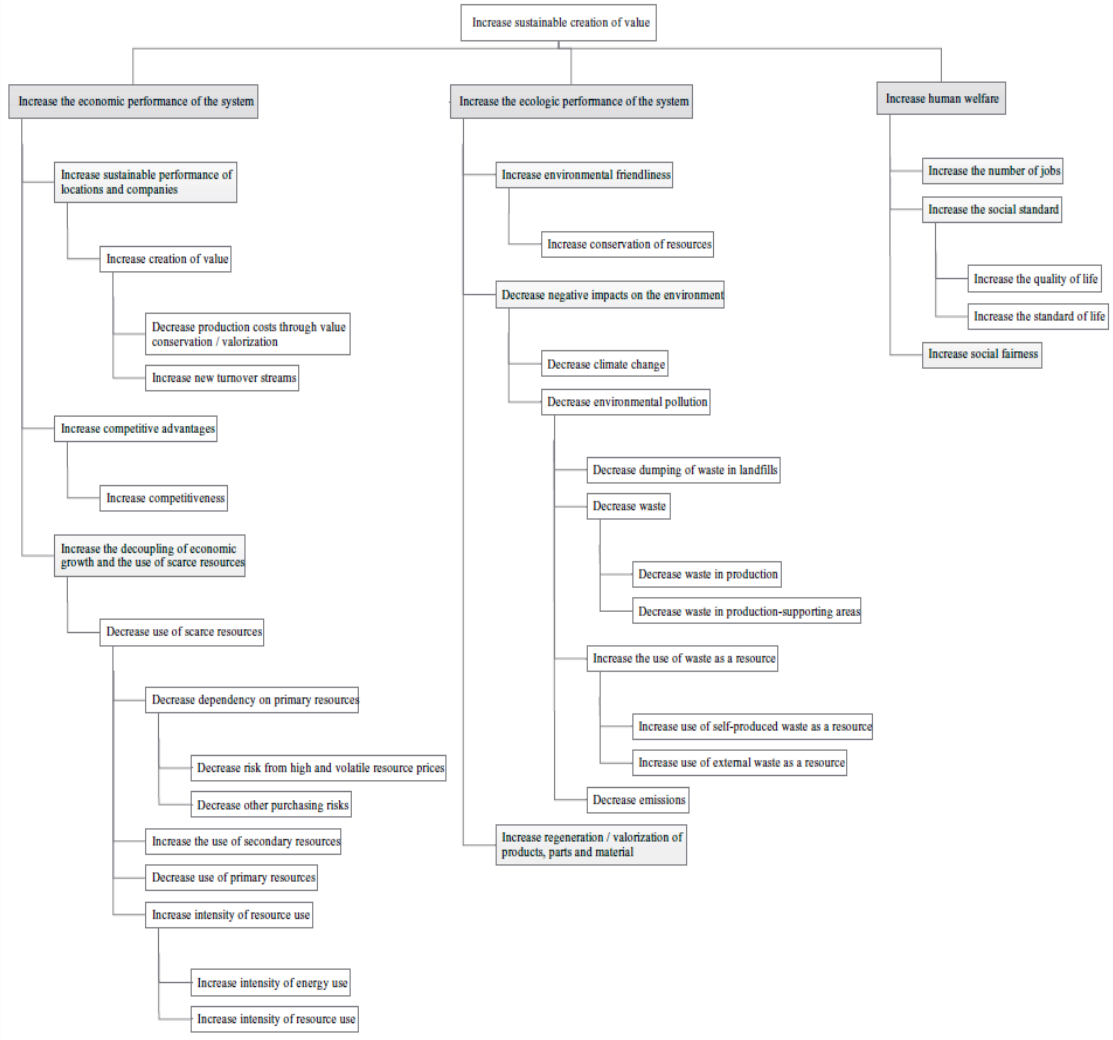
APPENDIX

APPENDIX A: Circular economy schools of thought

SCHOOL OF THOUGHT	DEFINITION/PRINCIPLES	SOURCE
Industrial Ecology by Graedel & Allenby (1995) Frosch & Gallopoulos (1989)	A study of material and energy flows through industrial systems. It aims to: • Create connections within a industrial ecosystem • Creation of closed-loop processes where waste is used as an input, • Eliminates the notion of an undesirable by-product. • Adopts a systemic point of view, • Design production processes in accordance to local ecological constraints whilst taking into account the global impact • Inspiration from natural living systems	Korhonen et al., 2018 Wautelet, 2018 Ghisellini et al.,2016 Winans et al., 2017 EMF, 2015 Millar, McLaughlin, & Börger, 2019
Cradle-to-cradle by McDonough and Braungart (2002)	A design philosophy which perceives the safe and productive processes of nature's 'biological metabolism' as a model for developing a 'technical metabolism' flow of industrial materials. Product components can be designed for continuous recovery and reutilization as biological and technical nutrients within these metabolisms. It is based on three main principles: • Eliminate the concept of waste • Power with renewable energy • Respect human & natural systems.	Korhonen et al., 2018 Wautelet, 2018 Geissdoerferet al., 2017 Winans et al., 2017 EMF, 2015 Millar, McLaughlin, & Börger, 2019
Sharing Economy	An economic model based on sharing underutilized assets from spaces to skills to stuff for monetary or non monetary benefits.	Korhonen et al., 2018
Ecological Economics by Boulding (1966) Georgescu-Roegen (1986) Daly (1997) Ring (1997) Robert U. Ayres (1999)	An interdisciplinary field defined by a set of concrete problems or challenges related to governing economic activity in a way that promotes human well-being, sustainability, and justice.	Korhonen et al., 2018 Winans et al., 2017
Performance Economy by Stahel (2010)	An economy which pursues four main goals: • product-life extension • long-life goods • reconditioning activities • waste prevention • selling services rather than products	Korhonen et al., 2018 Wautelet, 2018) Geissdoerferet al., 2017 Winans et al., 2017 EMF, 2015 Millar, McLaughlin, & Börger, 2019
Biomimicry by Benyus, 2002	Innovation inspired by nature: • Nature as a model • Nature as a measure • Nature as a mentor	Korhonen et al., 2018 Wautelet, 2018 EMF, 2015 Millar, McLaughlin, & Börger, 2019
Eco Efficiency by Welford (1998) Huppes and Ishikawa (2009) Haas, Krausmann, Wiedenhofer, & Heinz (2015)	It is based on creating of more goods and services with: • Less resources • Less waste • Less pollution.	Korhonen et al., 2018 Millar, McLaughlin, & Börger, 2019
Resilience Science by Holling (1973)	Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist.	Korhonen et al., 2018
Natural Capitalism by Hawken, Lovins, & Lovins (2008)	An approach that protects the biosphere and improves profits and competitiveness, through taking better and efficient advantage of resources. It suggests four major shifts in business practices: • Radically increase the productivity of natural resources • Shift to biologically inspired production models and materials • Move to a "service-and-flow" business model. • Reinvest in natural capital.	Korhonen et al., 2018 EMF, 2015
Cleaner Production by Ghisellini et al. (2016) Lieder and Rashid (2016) Stevenson and Evans (2004)	A company specific environmental protection initiative which aims to maximize product output by: • Minimize waste • Minimize emissions	Korhonen et al., 2018 Millar, McLaughlin, & Börger, 2019
Blue Economy by Pauli (2010)	An open-source movement which is based on the following principles: • Material and energy cascading systems • Ones waste is another ones income • Determination of solutions should be by local environment and physical characteristics • Gravity as the primary source of energy	Wautelet, 2018 EMF, 2015
General Systems Theory by Von Bertalanffy (1968)	A theory which suggests that complex systems have common organizing principles that can be identified and modeled mathematically. The theory promotes: • Holism • System thinking • Complexity	Ghisellini et al.,2016)

	• Organizational learning • Human resource development	
Silent Spring by Carson (2009)	A book which documents the adverse environmental effects caused by the indiscriminate use of pesticides.	Winans et al., 2017
Limits to Growth by Meadows, Meadows, Randers, & Behrens III (1972)	A report on the computer simulation of the exponential economic and population growth with a finite supply of resources. The purpose of the report is to • Gain insights into the limits of our world and the constraints it puts on human numbers and activity • Identify and study the dominant elements, and their interactions, that influence the long-term behavior of world systems	Winans et al., 2017
Regenerative Design by Lyle (1994)	A design approach which is based on two principles: • Processes themselves renew the sources of energy and material • Systems thinking	Winans et al., 2017 Geissdoerferet al., 2017 Millar, McLaughlin, & Börger, 2019
Industrial Symbiosis by Renner (1947) Robert U Ayres (1989) Chertow and Ehrenfeld (2012)	The process by which wastes of by-products of an industry or industrial process become the raw materials for another. It is based on: • Systems thinking • Mimic the function of ecological systems • Energy and materials cycle continually • No waste production	Geissdoerferet al., 2017

APPENDIX B: Hierarchy of circular economy objectives



APPENDIX C: Definition of Circular Business Models

SOURCE	DEFINITION
Roos (2014)	*"A circular value chain business model (or green business model) is one in which all intermediary outputs that have no further use in the value creating activities of the firms are monetized in the form of either cost reductions or revenue streams."*
Linder & Williander (2015)	*"A business model in which the conceptual logic for value creation is based on utilizing the economic value retained in products after use in the production of a new offerings. Thus, a circular business model implies a return flow to the producer from users, though there can be intermediaries between the two parties [. . . and] always involves recycling, remanufacturing, reuse or of their sibling activities (e.g., refurbishment, renovation, repair).*
Den Hollander & Bakker (2016)	*"A circular business model describes how an organization creates, delivers, and captures value in a circular economic system, whereby the business rationale needs to be designed in such a way that it prevents, postpones or reverses obsolescence, minimizes leakage and favors the use of 'presources' over the use of resources in the process of creating, delivering and capturing value."*
Nußholz (2017)	*"A circular business model is how a company creates, captures, and delivers value with the value creation logic designed to improve resource efficiency through contributing to extending useful life of products and parts and closing material loops."*
Geissdoerfer et al. (2018a)	*"CBMs can be defined as SBMs - which are business models that aim at solutions for sustainable development by creating additional monetary and non-monetary value by the pro-active management of a multiple stakeholders and incorporate a long-term perspective - that are specifically aiming at solutions for the Circular Economy, by incorporating elements that slow, narrow, and close resource loops, through a circular value chain and stakeholder incentive alignment."*

APPENDIX D: Circular strategies and circular business models for the Built Environment

SOURCE	CIRCULAR STRATEGY	CIRCULAR BUSINESS MODEL TYPE
Carra & Magdani (2016)	Circular Design	• Product and process design • Circular supplies
	Circular Use	• Tracking facility • Sell and buy-back • Lifetime extension • Product as a service • Sharing Platforms
	Circular Recovery	• Recovery provider • Refurbish and maintain • Recapture material supplies • Recycling facility
Kubbinga et al. (2017)	-	• Circular inputs • Product-service systems • Lifetime extension • Sharing platforms • Value recovery
Peters et al. (2017)	Product/component/material driven	• Non-toxic ingredients • Product/component substitution • Product life extension • Component reuse • Refurbish • Material recovery and reuse

Product performance driven	• Product as a service • Product performance as a service • Shared use
Building performance driven	• Design- build-operate • Finance-design-build-operate
Value network and collaboration driven	• Platform as a service • Software as a service • Insights as a service

APPENDIX E: Definitions of Product-Service Systems

REFERENCE	DEFINITION
Goedkoop et al. (1999)	*"A marketable set of product and services capable of jointly fulfilling a user's need. The PS system is provided either by a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. Product and service can be equally important for the function fulfillment"*
Manzini (2001)	*"A business innovation strategy offering a marketable mix of products and services jointly capable of fulfilling clients' needs and/or wants - with higher added value and a smaller environmental impact as compared to an existing system or product"*
Mont (2002)	*"PSS should be defined as a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models."*
Tukker (2004)	*"A system consisting of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs."*
Morelli (2006)	*"A PSS is a social construction, based on ''attraction forces'' (such as goals, expected results and problem-solving criteria) which catalyze the participation of several partners. A PSS is the result of a value co-production process within such a partnership. Its effectiveness is based on a shared vision of possible and desirable scenarios"*
Baines et al. (2007)	*"A PSS can be thought of as a market proposition that extends the traditional functionality of a product by incorporating additional services. Here the emphasis is on the 'sale of use' rather than the 'sale of product'."*
Neely (2008)	*"A Product-Service System is an integrated product and service offering that delivers value in use."*
Geng & Chu (2012)	*"Products and services are integrated and provided as whole set to fulfil customer's requirements, and the product/service ratio can vary in different customer using contexts"*
Boehm & Thomas (2013)	*"PSS is an integrated bundle of products and service which aims at creating customer utility and generating value."*
Reim et al. (2015)	*"PSS are defined as a marketable set of products and services that are capable of jointly fulfilling customers' needs in an economical and sustainable manner."*
Vezzoli et al. (2015)	*"An offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a 'unit of satisfaction'), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally and socio-ethically beneficial new solutions."*
Annarelli et al. (2016)	*"PSS is a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs."*

APPENDIX F: Eight types of Product-Service Systems

PRODUCT SERVICE SYSTEMS TRICHOTOMY		
THE PRODUCT-ORIENTED	THE USE-ORIENTED	THE RESULT ORIENTED
• ***Product-related service*** In this case, the provider not only sells a product, but also offers services that are needed during the use phase of the product, such a maintenance contract, a financing scheme or the supply of consumables or even a take-back agreement when the product reaches its	• ***Product lease*** In this case the ownership remains with the provider. At the same time, the provider takes up the responsibility for the maintenance, repair and control. The lessee pays a regular fee for the use of the product, and has unlimited and individual access to the leased product.	• ***Activity management outsourcing*** In this case a third party outsources a part of an activity of a company. Due to the fact that the majority of the outsourcing contracts involve performance indicators for controlling the quality of the outsourced service, they are grouped in this paper under result oriented

end of life.		services. However, in many cases the way in which the activity is performed does not shift dramatically. A typical example of this category is the office cleaning that is now a commonplace in most companies
• ***Advice and consultancy*** In this case the provider sells the product but also gives advice on its most efficient use. This may, for instance, include advice on the optimization of the logistics in a factory where the product is used as a production unit	• ***Product renting or sharing*** In this case the ownership stays with the provider, who is also responsible for maintenance, repair and control, and the user pays for the use of the product. The main difference to product leasing is, however, that the user does not have unlimited and individual access, since the same product can be used by other used at other times.	• ***Pay per service unit*** In this case the provider sells the output of the product according to the level of use.
	• ***Product pooling*** This greatly resembles product renting or sharing. However, here there is a simultaneous use of the product.	• ***Functional result*** In this case the provider agrees with the client the delivery of a result. The provider is, in principle, completely free as to how to deliver the result. Typical examples of this form of PSS are companies who offer to deliver a specified 'pleasant climate' in offices rather than gas or cooling equipment.

APPENDIX G: Expert Interview Questionnaire

INTERVIEW QUESTIONS FOR RESEARCH PROJECT

Foteini Koukopoulou – MSc Management of Technology

INTERVIEW GOALS

Gain insight into how actors perceive Product - Service Systems (PSS) as a Circular Business Model (CBM) for the built environment, its opportunities and challenges, as well as the enabling conditions to overcome the barriers.

INTRODUCTION

- **SUBJECT**

The thesis studies the Product as a Service Circular Business Model (PaaS CBM) for the built environment.

- **MAIN OBJECTIVE**

Explore the opportunities and challenges of the PaaS CBM's application for the materials, products, and elements in the different building layers, as well as the enabling conditions to overcome them. For the purpose of this study the 6S framework of Stewart Brand is used to break down the building in a collection of layers with each having its own lifespan, function, materials, products, and elements.

- **MAIN TOPICS**

  - Circular business models in the built environment
  - The product as a service circular business model for the built environment
  - Opportunities of the product as a service circular business model for the built environment
  - Challenges of the product as a service circular business model for the built environment
  - Enabling conditions to overcome the challenges of the product as a service circular business model in the built environment

- **DURATION**

The interview will approximately take 40-45 minutes

- **RECORDING THE INTERVIEW**

In order to support the scientific value of this thesis would it be ok for you to record this interview

INTERVIEW QUESTIONS

- **INTRODUCTION OF INTERVIEWEE**

  a. Who are you, what is your function your function, and organization?
  b. How do you work on CBM in the built environment?

- **CURRENT STATE & MAIN DEVELOPMENTS**

  a. What is a Circular Business Model (CBM) for the built environment?
  b. How can sustainability be integrated in CBMs for the built environment?
  c. What are the main developments for CBM for the built environment in the Netherlands?
  d. What are, according to you, the major types of CBM for the built environment?
  e. What is a Product as a Service Circular Business Model for the built environment?
  f. To what extent do suppliers perceive the PaaS CBM as an important CBM moving towards a circular built environment?
  g. What is their motivation to move towards PaaS CBM in the built environment? What are the barriers or constraints?
  h. How can sustainability be integrated in the PaaS CBM for the built environment?
  i. What are good cases or pilots of PaaS CBM in Netherland's built environment? Which ones do you know better or have you been involved into? Who is a good contact person/expert on this case?

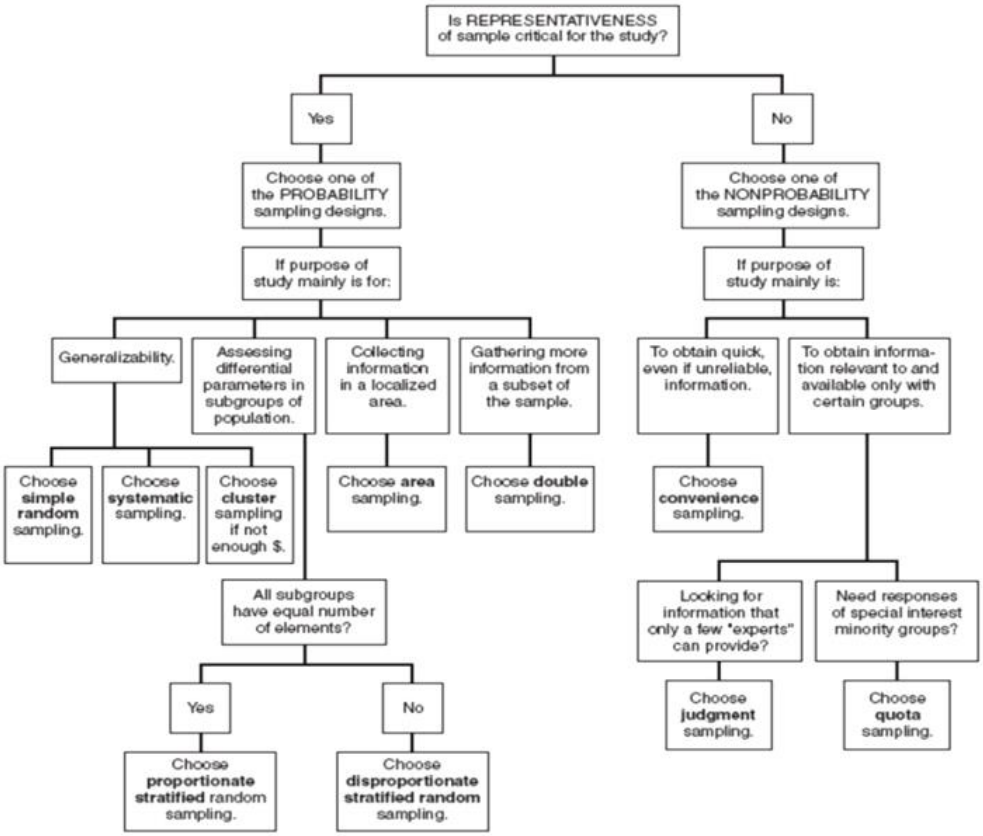
- **CHALLENGES & OPPORTUNITIES**

  a. Which type of PaaS CBM is more suitable/ feasible for the materials, products, and elements of the Building? Do you think different types are suitable for the different layers of the building (Skin, Service, Structure)?
  b. What are the opportunities of applying the PaaS CBM for materials, products, and elements of the Building? Do you think different opportunities arise for the different layers of the building (Skin, Service, Structure)?
  c. What are the challenges and barriers of applying the PaaS CBM for materials, products, and elements the Building? Do you think different challenges and barriers arise for the different layers of the building (Skin, Service, Structure)?
  d. What needs to change to overcome the challenges of applying the PaaS CBM for materials, products, and elements of the Building? Do you think the enabling conditions differ according to the building's layers (Skin, Service, Structure)? How can these enabling conditions be achieved?

- **CLOSING**

  a. Is there anything you would like to add on the application of PSS CBM for the built environment?
  b. Whom would you recommend me to contact for an interview?
  c. Any other remarks or feedback?

APPENDIX H: Choice of Sampling Method



APPENDIX I: Criteria for the Expert Selection

CRITERIA FOR SELECTION	EXPLANATION OF CRITERIA
Related to the research topic	The position of the experts needs to be related to CE and CBMs in the Dutch built environment, either directly or indirectly. Directly meaning that their everyday work is focused on CE and CBMs in the built environment. Indirectly meaning that they have been involved in projects which concern these concepts, but their activities in their organizations may not always focus on CE and CBMs in the Dutch built environment or have been involved in the past.
Educational background	Inclusion of experts with varying backgrounds is important since people with different education will have different knowledge, skills, and information on the topic under investigation; thus interviewing them enables the researcher to incorporate different views and perspectives. For instance, experts which have a background in law may lack technical knowledge, and experts with a background in industrial engineering may lack knowledge regarding policies and regulations.

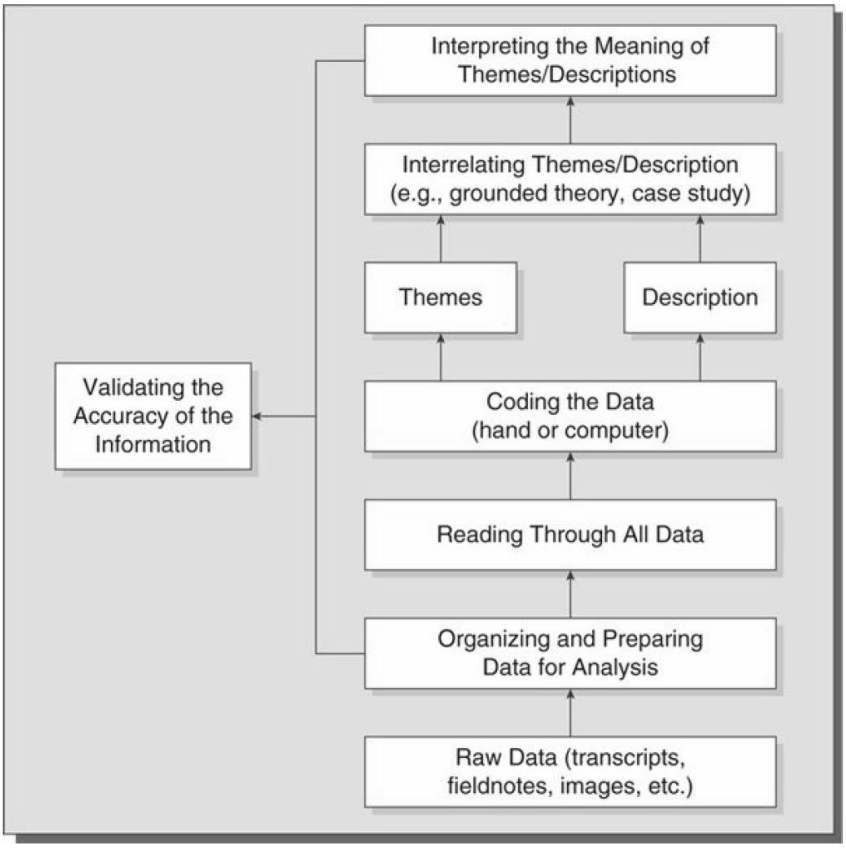
Work experience	Experts with different working experience were selected, since they will have as well a different perspective on the subject, and thus will share different knowledge and information. In addition, the answers of each participant will be guided by their expertise and experiences which result from their actions, responsibilities, obligations of the specific functional status within an organization.
Position	According to Van Audenhove (2007), experts in higher positions may have a good overview of the subject, but may lack expert knowledge on issue of interest. In addition, experts in top positions may be over committed and thus have less time to devote. On the other hand, experts on lower levels might have more detailed knowledge on the topic under investigation
Level of public recognition	Experts with different levels of recognition were chosen for this study. A number of the ones which were contacted were authors of papers and reports others were identified from events, conferences, or interviews on the topic under investigation. However, inclusion of experts with less public recognition was also aimed; thus, some of the experts which were contacted and interviewed have been working on CE, CBMs, and/or PSS in the Dutch built environment without being in the public eye.
Country	Since the study focuses on the Dutch built environment the aim was to identify experts in the country of the Netherlands. Experts active in other countries may not have the insights required for this study, since trends a number of aspects, such as market developments, regulations, practices and trends of the building sector may differ from country to country. However, a small number of experts which are working on the topic in other countries were contacted, since even though they might not have been able to provide insights regarding the Netherlands, their knowledge and information on the topic could be valuable for this research.

APPENDIX J: Advantages and disadvantages of interview methods

FACE TO FACE INTERVIEW	
Advantages	**Disadvantages**
• Social cues, such as voice, intonation and body language, disclose extra information, • Interviewer can create a good interview ambience, due to synchronous communication in time and place • Termination of interview is easier since enough clues can be given that the end of an interview is near • Interviewee is more spontaneous, due to synchronous communication in time • Standardization of the interview	• Visibility can lead to disturbing interviewer effects • Synchronous communication of time and place can bring with it a lot of time and costs.
PHONE INTERVIEW	
Advantages	**Disadvantages**
• Social cues, such as voice and intonation disclose extra information • Time and money saving, due to asynchronous communication in space • Interviewee is spontaneous, due to synchronous communication in time • Wide geographical access	• Less possibilities to create a good interview ambience since the interviewer has no view on the situation in which the interviewee • Reduction of social cues, namely body language due to asynchronous communication in space • Less standardization of the interview
VIDEO CONFERENCING	
Advantages	**Disadvantages**

• Wide geographical access • Social cues, such as voice, intonation and body language • Time and money saving, due to asynchronous communication in space • More possibilities to create a good interview ambience, since the interviewers has view on the situation of the interviewee • Interviewee is spontaneous, due to synchronous communication in time	• Visibility can lead to disturbing interview effects • Less standardization of the interview

APPENDIX K: Qualitative Analysis

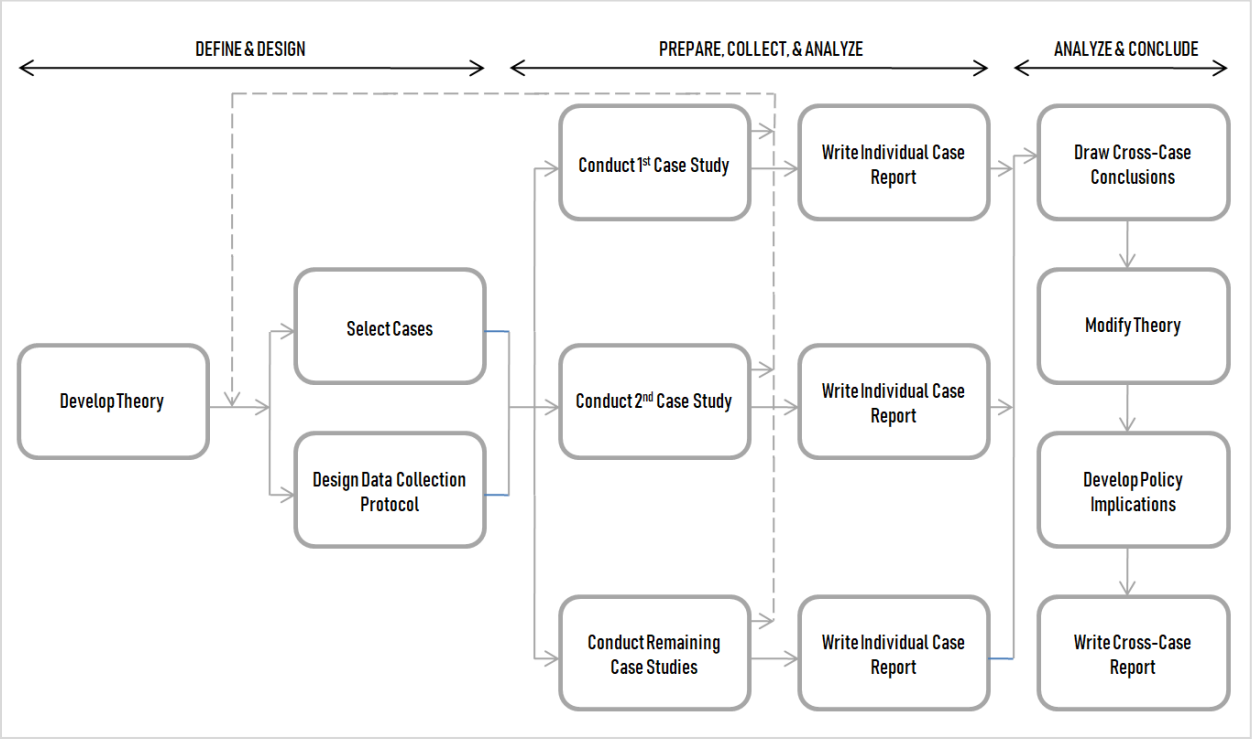


APPENDIX L: Case study design steps

CASE STUDY DESIGN STEPS	EXPLANATION
Unit of analysis	• It is related to the fundamental problem of defining what the case is. • It is closely related to the research question which the case study is aiming to provide an answer to.
Determination of the type of case	• It is guided by the overall study purpose • There are three main categories: i. Explanatory "This type of case study is applied if the research aims to explain the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies."

	ii. Exploratory "This type of case study is used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes" iii. Descriptive "This type of case study is used to describe an intervention or phenomenon and the real-life context in which it occurred"
Binding the case	• The placement of boundaries is suggested, and advices on how to avoid this involve: 4.1.1 By time and place 4.1.2 By time and activity, or 4.1.3 By definition and context
Single case or multiple case study	• The single case study as the best choice among the two options if the researcher only wants to study one single thing or a single group. • The multiple case study is conducted when for the purpose of a research more than one case is examined

APPENDIX M: Multiple case study design



APPENDIX N: Case study questionnaire

INTERVIEW QUESTIONNAIRE FOR CASE STUDY

CASE STUDY GOALS

Analyze the business model of suppliers of building products, components, and materials, who have already successfully established Product Service Systems as Circular Business Models in the Dutch Built Environment.

INTRODUCTION TO THESIS SUBJECT

- **INTRODUCTION TO THE THESIS SUBJECT**
  The thesis studies the Product as a Service Circular Business Model (PaaS CBM) for the built environment.

- **CASE STUDY'S MAIN OBJECTIVES**
  - Gain insights of how building product, component, and material suppliers view the PSS as CBM
  - Analyze the business model of building products, components, and material suppliers
  - Explore the opportunities, challenges of the implementation of the PSS as a CBM

- **DURATION**
  The interview will approximately take 40-45 minutes

- **RECORDING THE INTERVIEW**
  In order to support the scientific value of this thesis would it be ok for you to record this interview

INTERVIEW QUESTIONS

- **INTRODUCTION OF INTERVIEWEE**

a. Who are you, what is your function, and organization?
b. What is the type of your company?
c. How do you or your organization work on CBM and PSS?

- **GENERAL QUESTIONS**

a. What is the PSS as a CBM in your view?
b. What was the motivation of your organization to implement the PSS as a CBM? Why do you consider it as an important business model for your company?
c. What were the challenges during the process? What were the benefits? What were the success factors?
d. Will you expand the PSS your company has established as a CBM? Why or why not?
e. How many PSS as CBM does your firm have?
   -If there is only one: Are you thinking on applying it in other parts of your company? Why or why not?
   -If there is more than one: Which one do you consider your most successful one and why?

- **VALUE PROPOSITION**

a. How do you describe your value proposition?
b. How do you ensure circularity in your value proposition?
c. Has extra value been created for the environment or society?
d. What type of PSS has your company established?
e. What are the services you provide with the product?

- **CUSTOMER RELATIONS**

a. What describes the types of relationships your company establishes with its customers?
b. How does circularity and servitization affect the customer segments? How you do you ensure it?

- **CUSTOMER SEGMENTS**

a. What are the main groups of people or organizations your company aims to reach and serve?
b. How does circularity and servitization affect the customer segments? How you do you ensure it?

- **CHANNELS**

a. What are the key channels your company uses to communicate with the customer?
b. How does circularity and servitization affect the communication of the value proposition? How you do you ensure it?
c. What are the key channels the company uses to deliver the value proposition?
d. How does circularity and servitization affect the delivery of the value proposition? How you do you ensure it?

- **KEY PARTNERS**

a. Who are the main partners/actors in your network and what is their role in supporting your company?
b. What resources and activities does the company acquire from partners?
c. How does circularity and servitization affect the choice and role of the partners? How you do you ensure it?

- **KEY ACTIVITIES**

a. What are your company's key activities for supporting your business model?
b. How does circularity and servitization affect the key activities? How you do you ensure it?

- **KEY RESOURCES**

a. What are your company's key resources for supporting your business model?
b. How does circularity and servitization affect the key activities? How you do you ensure it?

- **COST STRUCTURE**

a. How is the cost structure of your company's business model? Where do the main costs occur?
b. How does circularity and servitization affect the cost structure of your company?

- **REVENUE STREAM**

a. How is the revenue stream of your company's business model? Where do the main revenues occur?
c. How does circularity and servitization affect the revenue stream of your company?

- **ADOPTION FACTORS**

a. Are there any specific organizational capabilities you had to build in order to support your business model?
b. How does circularity and servitization affect your organizational capabilities?
c. Are there any external factors, such as political, environmental, socio-cultural, technological, affecting your business model?

- **TAKE-BACK SYSTEM**

a. How do you manage your take-back systems? How does it affect the channels and the customers' relations?
b. How does circularity and servitization affect your take-back systems?

- **FUTURE IDEAS**

a. Do you have any plans to further develop your PSS CBM? i.e how to enhance its circularity
b. Which do you consider the next step regarding the PSS CBM in general?
c. What are the challenges in realizing that future? How can it be facilitated?
d. What should or could other actors and/or the government do to facilitate PSS for more circularity?

APPENDIX O: CBM and PSS business model canvas elements

CIRCULAR BUSINESS MODEL CANVAS	
Value propositions	• Involves product-service system, virtualized services, collaborative consumption and the incentives offered to the client for bringing back the product is analyzed.
Customer segments	• A direct connection between this element and the value proposition one exists, since the latter ones highlights the fit between the customer segment and value proposition.
Customer relations	• Includes the customers involvement in decisions, social-marketing strategies and relationships with community partners when recycling 2.0 is implemented.
Channels	• Includes the selling and delivering through virtual channels, and virtualization can also be applied for the company's communication with the client.
Revenue stream	• Payments are made for delivering availability, use, or performance related and additional revenues may come from the retrieved resources value.
Cost structure	• Includes the value of incentives for customers, as well as particular criteria for accounting and evaluation.
Key resources	• Includes better-performing materials, virtualization of materials, the selection of resources which are in line with circular economy enabling the regeneration and restoring of natural capital, and/or the resources obtained from customers or third parties meant to circulate in material loops, which preferably are closed.
Key activities	• Includes performance through good housekeeping, better process control, equipment modification, technology changes, sharing and virtualization, design improvement of the product for material loops, and becoming more eco-friendly. Key activities might also comprise lobbying
Key partners	• Involves the choice and collaboration with industry partners, along the value chain and supply chain, which support the implementation of circular economy
Take-back system	• Involves the development and design of the system which support take-back, and includes channels and customer relations.
Adoption factors	• Recognizes that the transition towards circular business model must be supported by various organizational capabilities and external factors.
PRODUCT-SERVICE SYSTEMS BUSINESS MODEL CANVAS	
Value propositions	• Involves a combination of products and services and includes elements such as lower responsibility of customer during the product's lifecycle, the provision of guarantee for function, offering reduced cost of manufacturing operations, for instance when the client is another company.
Customer segments	• Includes different customer segments with different perceptions regarding ownership. This conception differs according to the region, the culture, and the consumer's habits, values, as well as behaviors.
Customer relations	• Requires direct relations and intensified contacts with customers, to enable long-term relationships. In order to build closer relationships with customers, operational links, information exchange, legal ties and the establishment of cooperative rules are suggested.
Channels	• Sales and retail should be able to promote product-service systems, and building it more attractive than a product-based option. In order for the company's staff to achieve that training is required, as well as recruiting new ones. Finally, another important aspect is to "sell the idea" through marketing campaigns that highlight the advantages of PSS

Revenue stream	• Involves the creation of new revenue models based on performance-based pricing. Payments can be made based on availability, usage, and end result. However, in a network, revenue distribution must be well managed to avoid misunderstandings.
Cost structure	• Arranged to support a new demand of cash-flow. In PSS, the payback period of the value delivered is often longer than the payback period of physical product sales.
Key resources	• In order to support the PSS, suppliers and providers need to significantly invest in different areas, varying from human assets, to culture and as well as infrastructure.
Key activities	• Includes the shift of focus from activities which are related to physical products and pay close attention and extra effort on services. With PSS, a dependency is created between company's operations and customer's activities
Key partners	• Involves a complex network of suppliers and competencies. It requires the identification of actors and of the core competencies they can provide. Moreover, partnership design requires the specification of each partner's value and contribution throughout the product's lifecycle

APPENDIX P: Structure layer – Interview quotes as examples for barriers

STRUCTURE LAYER - Barriers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**
Finance & Economic	*FINANCING ISSUE* *"The lifespan in economic sense is too long. It takes about 50 years or maybe longer and for a bank this is very difficult to finance. Contracts for a loan are 10, maybe 30 years, not for 50 years. It's too difficult to measure all the risks for such a long period." (Expert H)*
	VALUATION OF PCMs *"We don't have the examples at the moment of what the value is at the end of the components or the whole thing. So that is something that we are working on with markets and the companies to see how you can value it at the end of life, but we don't really have a definite answer yet. We're trying it but it's definitely a challenge." (Expert K)*
The PCMs involved in the Layer	*CONCRETE* • *"Well, for the technical products I think there could be a market, but for raw materials, for the concrete, I don't see it as a real possibility." (Expert H)* • *"So maybe not make it from concrete or make it from something else that can be reused, maybe from steel or from aluminum." (Expert I)* • *"A lot of customers are anxious not having the concrete structure of a building on their own balance sheet. So, I don't think that the concrete structure is really going to be successful in a deliberate as a product or service." (Expert D)*
	STEEL • *"But it is a bit of a challenge if you use a lot of used products from a building and you put them in a new building it has to be safe if it's something that has to hold the roof up, So how do you test that? Who says it's safe?" (Expert K)* • *"In the case of steel beams you need sensors to say how much it has been loaded over the last 15 years to know if It's still structurally reliable; but this requires a huge display of technology that might be incredibly expensive and therefore will just completely ruin the business case. In that case because the intrinsic value of it is not that huge then maybe recycling it is easier to justify from an economic perspective then having all this technology and all this history of a component to see how it has been used." (Expert G)*

Part of the Structure	FOUNDATION *"What you see with financiers and banks is that the place where the building is put is what makes it interesting. So as a bank you don't mind when the building moves, but the understructure you want to keep. That's where you make the money in Amsterdam." (Expert K)*
Lack of Maintenance and Performance Services	*LACK OF UPDATING* *"There is not a lot of updating going on in the main structure of the buildings" (Expert H)*
Policy & Legislation	*DUTCH PROPERTY LAW* *"Legal barriers because the structure belongs to the building site and it's called property. In Dutch we have the term immovable good. So you cannot actually have someone else be responsible for the structure because it cannot be from someone that is not related to the site." (Expert B)*

APPENDIX Q: Structure layer – Interview quotes as examples for enablers

STRUCTURE LAYER - Enablers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**
Implementation of PSS for Temporary Structures	*TEMPORARY BUILDINGS* *"I think for the structure it is possible only if you talk about very specific cases of temporary structures, like popup parking lots or temporary housing…In general the shorter the period of the service life of the product the more likely it is to be used." (Expert G)*
Definition of Services for the Layer	*DEFINITION OF SERVICES* *"Define better what service means for the layer" (Expert M)*
	PERFORMANCE BASED SOLUTION FOR TEMPORARY STRUCTURE *"If you have a mobiliary that has to be replaced every four or five years and if you managed to implement a performance based solution with which you are reclaiming those materials you are making way more of a difference because otherwise it would be much more waste that would be generated." (Expert G)*

Design & Engineering	DESIGN FOR DISMANTLING • *"I think if you design in a way that you can dismantle it without too much damage to the product and environment think it can be applied for the structure of the building"(Expert K)*
	PLATFORM FOR FOUNDATION • *"Of course some parts I have to put them into the ground. For this a solution might be to think about making a platform that has to have additional stability so we can also build higher rise buildings." (Expert I)*
	STANDARDIZATION • *Steel structures are really standard, so from that perspective, implementation of product service systems could be easier" (Expert G)*
	VALUE OF RAW MATERIAL AND TECHNIQUE • *"When the main structure is made of steel, then of course I want of course to invest in it, because for sure in 30 years from now the steel will be worth much more. So it's not only about the technique, but also the value of the raw material" (Expert D)*
Technology	*NEED FOR NEW TECHNOLOGIES* *"There is need to develop new technology that is linked to a 4D model of the component and keeps track not only of the materials and the technology embedded that is embedded but also the service life it has received. Because then you can see, how often it has been maintained and that helps you see how reliable it is. In the case of steel beams you even maybe need like a sensor to say how much it has been loaded over the last 15 years". (Expert D)*
Policy & Legislation	*DUTCH PROPERTY LAW* *"Legal barriers because the structure belongs to the building site and it's called property. In Dutch we have the term immovable good. So you cannot actually have someone else be responsible for the structure because it cannot be from someone that is not related to the site." (Expert B)*

APPENDIX R: Skin layer – Interview quotes as examples for barriers

SKIN LAYER - Barriers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**
Finance & Economic	LACK OF FINANCING • *"They cannot pre-finance it themselves because they don't have the financial power for it or maybe they have for one, two or three facades, but they will never be able to make a long term ongoing business of leasing facades. It's very difficult in may different ways. Banks of course cannot just jump into it because banks are based on risk ratings. There's no history of leasing facades, and basically for now the track record is zero. So of course now the risk is incredibly high therefore they have to give a high interest rate." (Expert H)*
	BANKERS PERCEPTION • *"Bankers have to come up with a way of managing to be able to evaluate them and financing them in a more attractive way, because at the moment I think they are just perceiving them as a different type of mortgage." (Expert G)*
	SERVICING MORE EXPENSIVE • *"But if he rented the facade and the tree didn't fall to the facade all those he spent money for risk which in the end he didn't use." (Expert E)*
	DIFFICULTY DEFINING WHICH PARTY PRE-FINANCE THE FACADES • *"Approaching university clients because they get the advantage that they have a very long term planning. So either universities or governments or any of these parties, they can look ahead for*

	20 or 30 years and they can say "we're going to use this building for another 20 or 30 years", whereas commercial parties sometimes have a hard time thinking two or three years ahead, let alone 20 or 30. But then also by definition, these parties (government and universities) also have the best credit rating. For example, universities or government can borrow money at extremely low credit courses, which means that them is not very attractive to borrow money. In the case of leasing components because then probably their financial costs will be much higher than the financial cost of just paying for it themselves with money that they can borrow at really low credit ratings. On the other hand, they will be there. So they are the ideal target market, but on the other hand they are the least likely to be attracted by the financial argument."
Policy & Legislation	*DUTCH PROPERTY LAW* • *"Property law is based very much on the idea that to retain the value of a property, you have to retain the property in a fully functional shape and that's more likely to be guaranteed if it's all owned by the same party. And so that's why you have these things…Everything that is fixed to the building becomes property of the building owner, because it's perceived that this way it's less likely that you will go into financial troubles, and everyone will be taking their materials out, which will result in a non operating building that will lose its value." (Expert G)*
	VALUE ADDED TAX • *"The product will be the same for multiple cycles, but we will be charging value added taxes in each cycle, which is not logical." (Expert J)*
	BOUWBESLUIT • *"At the end of a lifetime the skin, the facade, if you hand it over in and put it on a new building, then it doesn't match the Bouwbesluit norm anymore" (Expert F)*
Knowledge & Culture	*INTERFACE PROBLEM* • *"Let's say a huge problem of facades if you go into the indoor comfort being all energy performance being the performance or the functionality you're delivering, because there are very likely to be delivered by different parties, because normally facade companies make facades and service installation companies make the installations, then they can always have the sort of the free card to use that it's the other person's fault, like "my facades is working perfectly, but the building services are not what they said it would be". Then you will have a lot of these problems on the interface between the different companies." (Expert H)*
	CONSERVATIVE STEEL BUSINESS AND SECTOR • *"But the steel business is a very conservative business and also the building industry as a whole is very conservative." (Expert J)*
	OLD LINEAR ECONOMY WAY OF THINKING • *"In fact, steel can be up cycled and aluminium will be down cycled. But we don't want to go into recycling. We say no, you have to reuse the profiles and the elements which have a very long technical lifespan and you can reuse them. So we can really perform maybe twice as good aluminum. But then there is a problem that everybody thinks "well, it just looks the same as aluminum". So we go for the cheaper product, which is the aluminum one". So this is the old linear way of thinking." (Expert J)*
	LACK OF INFORMATION • *"One of the main gaps that we find is that real estate managers at the moment don't have the information of how much they're spending on managing each component. So how much they spend on managing elevators or managing facades. They just collect all their expenses and at the end of the year they say "we spend this much, we gained this much". So when you come to them with a solution that is clearly more expensive and then the values will be seen in the long term, we don't really have the tools to balance that new proposal against the current one." (Expert G)*

APPENDIX S: Skin layer – Interview quotes as examples for enablers

SKIN LAYER - Enablers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**
Definition of Service & Performance Element for the Layer	*DELIVER PERFORMANCE* • *"Consider the key performance indicators on goals for functionality, not only the materials". The expert further explains that this can be done for instance, if "you deliver comfort in a room using a good façade with technology".*
	DEFINITION OF SERVICES • *"Define better what service means for the layer" (Expert M)*
Finance & Economic	*INVESTORS WITH A LONG TERM VISION* • *"There are investors with money to spend because they don't get the returns of their investments if they put their money in the bank. So they're looking for a high value property, which will remain on the highest level of quality. In that sense they can really get their returns in the long term. So we don't want investors who want to go short or want to invest for one year. We need financial investors for maybe five years or 10 years." (Expert J)*
	DEVELOPMENT OF GUARANTEES • *"How do I know that your company still exists in 10 years, so we have a contract. But, well what about the service agreement? What about the guarantees? So, that's another reason why I believe in, working together with other producers in an investment company because then the total will be able to deliver more guarantee in the future and more guarantee and money and more guarantee and technique." (Expert D)*
Technology	*BUILDING MANAGEMENT SYSTEM* • *"I think they need quite some technological improvement still in terms of live monitoring, for example, the connectivity for the facade components to building management systems. These kind of technologies to be able to have enough information to commit to more advanced form of product service system." (Expert G)*
	HARVEST MAP • *"So we decided, we wanted to go into the circular economy and we've been pioneering a lot. We have been trying out with multiple cycles for small elements, we have of overstock material, and our own harvest map which is not public yet. So we use it for our own purposes. On this map we can indicate where there's material available and we are experimenting in offering that to potential customers." (Expert J)*
Policy & Legislation	*CONTRACTING* • *"So, basically in order to preserve the value of the property the whole building law is based on not separating ownership of components. So for example, in our case we had to work with very specific constructs using all kinds of like apartment law and the right of leasehold, and all kinds of other measures, which are not the default ones. When just contracting the building you in order to be able to split the ownership of the facade and keep it in the hands of the supplier." (Expert G)*
Knowledge & Culture	*COLLABORATION* • *"If you want to go fast, you go alone; if you want to go far, you go together. We need to go far". (Expert J)*

	GOOD FLOW OF KNOWLEDGE • We had two very brilliant students from the TU Delft also who performed their thesis on the circularity of our facade system. And the last one was a guy who started off on the conclusion of the first lady. So we had very good flow knowledge and we found that we are maybe already supplying a very circular system in steel". *(Expert J)*
Design & Engineering	*REVERSIBLE DESIGN* • *"So that means that we also need to invite architects to our platform because they are the designers and they need to design in a reversible way so that they already know that after a short lifespan or a long lifespan that you need to take it away as easily as possible." (Expert J)*
	MECHANICAL CONNECTIONS-MODULAR DESIGN • *"We are maybe already supplying a very circular system in steel, as long as we don't weld, because every welded connection is for 100 years. So we try to supply facades in only mechanical connections" (Expert J)*
	CONSIDERATION OF EoL AT THE INITIAL PHASE • *"So if you think of a project then you always think the demolition company will come in 100 years. They'll take it away and then let's see what we can do with it. Then we said, you should really think of the demolition company at the start of the project not at the end. So we said, "well, let's try and put them in front of the process of the circular demolition companies" (Expert J)*
Supply Chain	*EXPERIMENTATION WITH REVERSE LOGISTICS* • *"If we can get a reverse logistic in our network that would be a huge step forward". (Expert J)*

APPENDIX T: Services layer – Interview quotes as examples for barriers

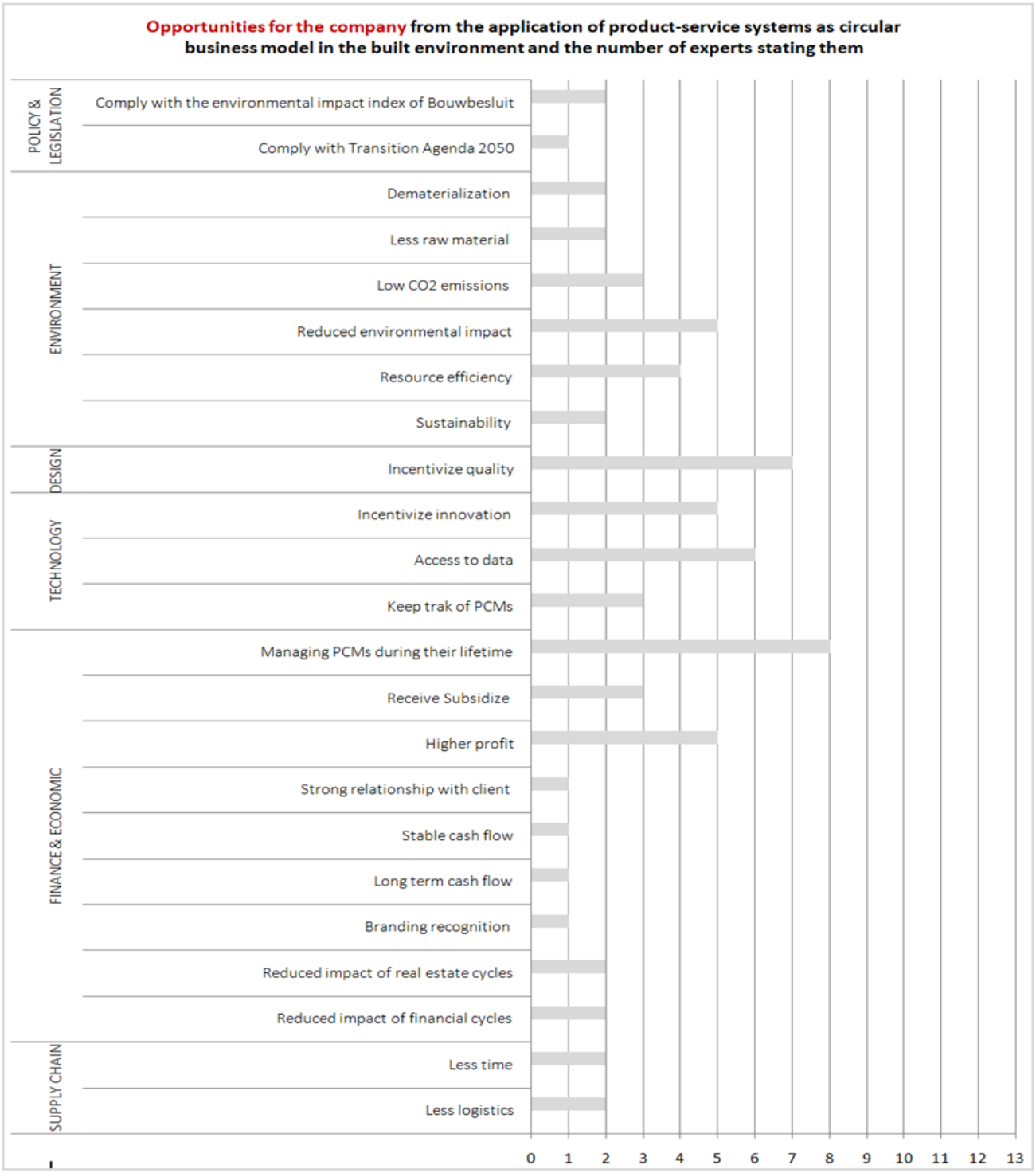
SERVICES LAYER - Barriers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**
Knowledge & Culture	*SUPPLIERS ARE VERY TRADITIONAL* • *"It's still takes some time because suppliers are really traditional, even more than maybe some other parties in the building sector. So they know, but it's still not there." (Expert B)*
	LACK OF INFORMATION • *"One of the main gaps that we find is that real estate managers at the moment don't have the information of how much they're spending on managing each component. So how much they spend on managing elevators or managing facades. They just collect all their expenses and at the end of the year they say "we spend this much, we gained this much". So when you come to them with a solution that is clearly more expensive and then the values will be seen in the long term, we don't really have the tools to balance that new proposal against the current one." (Expert G)*
Policy & Legislation	*DUTCH PROPERTY LAW* • *"When you want to have an elevator working as a service, then in this example, they even had to redefine the ownership of a part of the building in which the elevator is working in." (Expert D)*

APPENDIX U: Services layer – Interview quotes as examples for enablers

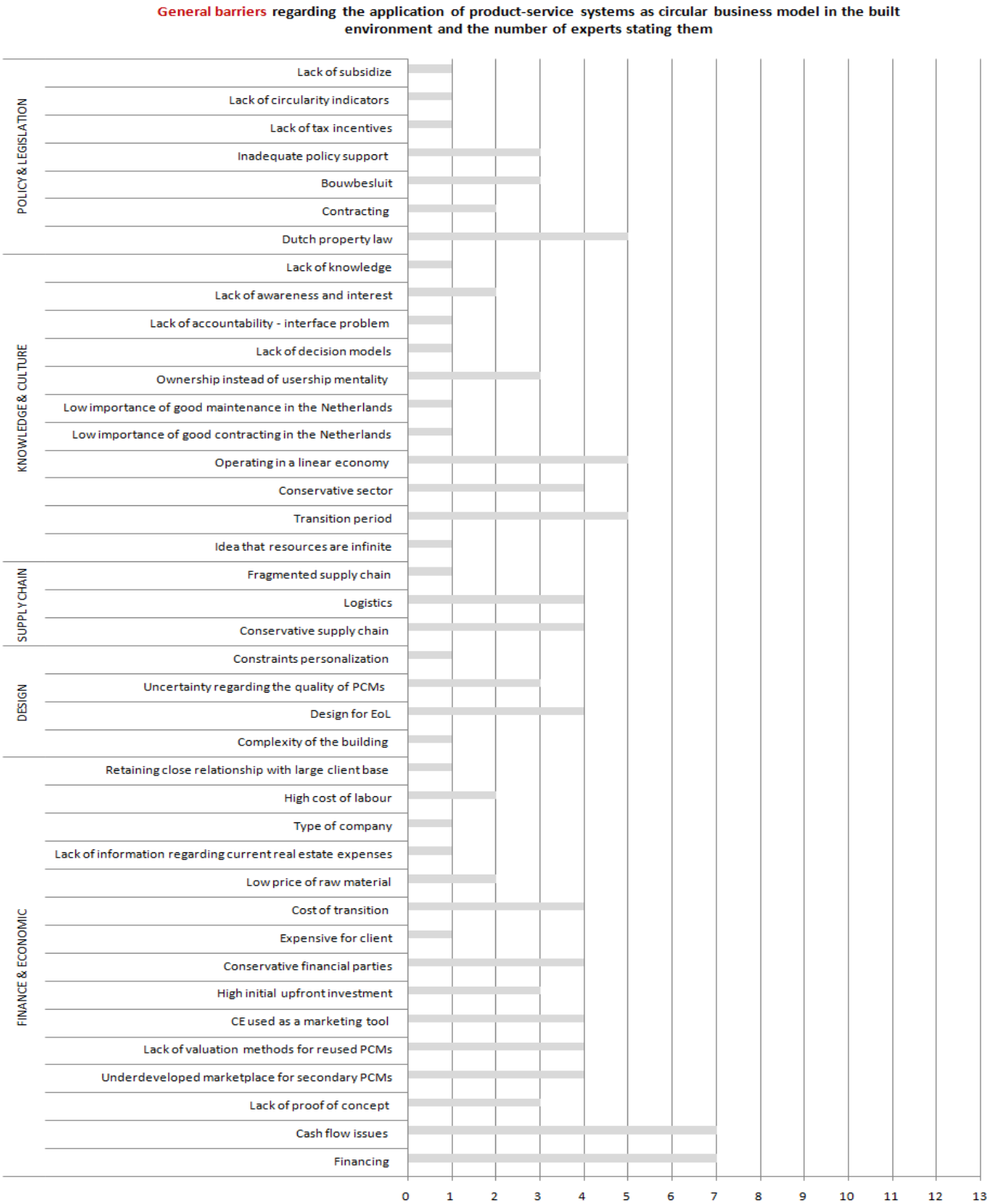
SERVICES LAYER - Enablers	
CATEGORY	**INTERVIEW QUOTES AS EXAMPLES**

Knowledge & Culture	*SENSOR TECHNOLOGY* • *"Technology gives a chance to product as a service. Through the sensors implemented on the elevator the owner can check at his own desk when the elevator needs maintenance. And so that's also a way that technology can help for product as a service." (Expert H*)
Design & Engineering	*EASILY ACCESSIBLE FOR MAINTENANCE* • *"They put all the installation on the outside, which makes it very easily accessible for maintenance workers and service workers. So if you want to upgrade your installation you can still live there." (Expert I)*
Policy & Legislation	*DUTCH PROPERTY LAW* • *"When you want to have an elevator working as a service, then in this example, they even had to redefine the ownership of a part of the building in which the elevator is working in." (Expert D)*
Finance & Economic	*OPTIMIZATION OF TOTAL COST OF OWNERSHIP* • *"So basically it is important to create new value to properties that are foreseen with PaaS models. The total cost of ownership will be optimized; the function will be constantly at a high level of performance. Instead of downgrading the expected value due to this ownership issue we need to create extra value because of PaaS implementation." (Expert C)*

APPENDIX V: Opportunities for the company

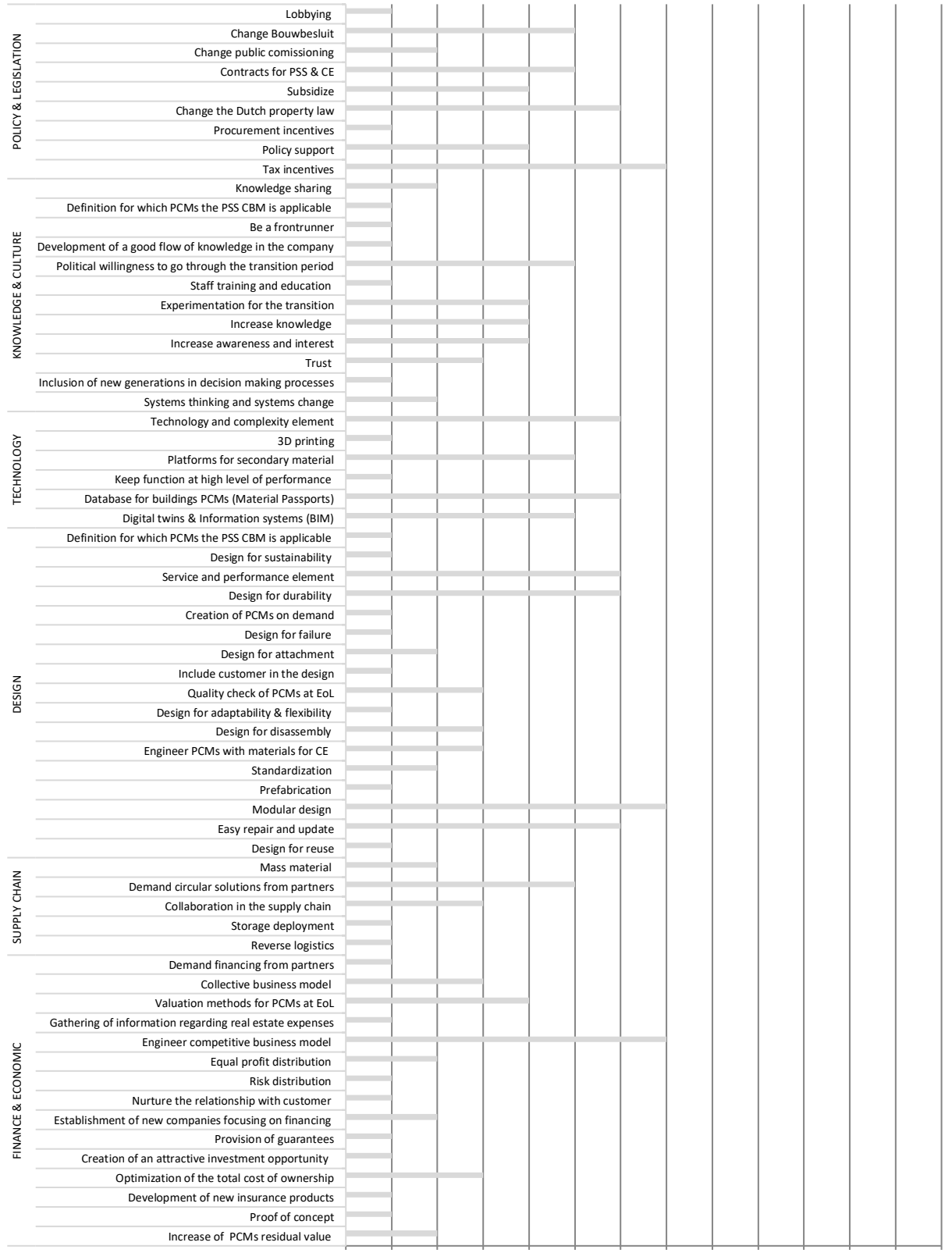


APPENDIX W: General Barriers



APPENDIX X: General Enablers

General enablers regarding the application of product-service systems as circular business model in the built environment and the number of experts stating them



APPENDIX Y: Recommendations for each actor in the built environment

STAKEHOLDER GROUP	ACTOR	ROLE
OWNERS & PLANNERS	Developers	• Demand circular solutions from their partners:
	Real Estate Investors	• Have a long term vision and plan. • Invest in the different layers in order to reduce the risk. •
	Financers	• Provide financial support to companies which apply the PSSs as CBMs.
	Owners	• Embrace new ownership models and CE in the built environment, by gaining knowledge regarding the opportunities offered by the shift. • Understand the value in outsourcing activities in order to understand the overall value offered by the PSSs as CBMs.
	Users	• Embrace new ownership models and CE in the built environment, by gaining knowledge regarding the opportunities offered by the shift.
	Facility Managers	• Retain close relationship with suppliers who operate with PSSS as CBMs • Use technological tools (BIM) to keep track of PCMs and assess when maintenance is required
DESIGN & BUILD TEAM	Architects Designers Engineers Consultants	• Collaborate with all parts of the supply chain in order to realize the circular built environment • Design PCMs in accordance to circular and servitization principles, such as low key and easily reachable for maintenance, modular design, and ensure standardization • Ensure during construction that the • Consultants should guide companies who want to apply the PSS CBM to make the right choices. For instance, facilitating the change of their calculation of Total Cost of Ownership and include socio-economic and environmental impact.
	Contractors Builders	• Work closely with architects, designers and engineers. • Follow the design and engineering rules provided by the architects, designers, and engineers. • Train their labor force in order to ensure that circularity is applied in the PCMs in the different layers. • Provide the PSS CBM for PCMs in the different layers of the building.
SUPPLIERS & MANUFACTURERS	Suppliers Vendors Manufacturers	• Apply the PSSs as CBMs, and engineer it to be competitive against the linear alternative. Pay attention to the value proposition which offered, an ensure high quality PCMs, low responsibility for the client, optimize total cost of ownership, monitor residual value, and
	Distributors	• Implement the PSSs as CBMs and demand transparency regarding the PCMs specifications in order to ensure that it aligns with CE principles.
	Installation Companies	• Establish the PSSs as CBMs or collaborate with suppliers, vendors, and manufacturers in order to support this business model moving towards CE in the built environment.
RECOVERY SPECIALISTS	Deconstruction & Demolition Companies	• Work closely with engineers, designers, architects in the initial the design phase in order to enable reuse of PCMs for the different layers of the building. • Disassembly or deconstruct PCMs at the EoL, therefore, avoid demolition in order to enable reuse. • Collaborate with suppliers in order to provide them with PCMs which become available in order to give them a second life.
	Waste Management Companies	• Enable high quality recycling for the PCMs that cannot be reused. • Collaborate with suppliers in the network in order to recycle the PCMs they take-back at the EoL or at the end of the contract period.
GOVERNMENT & CITIES	Regulators & Legislators	• Create a level playing field by formulating policies and regulations which can support the PSSs as CBMs specifically, and the CE in general. These can focus on changing the Dutch property law; create strict standards regarding the environmental performance of a building, lower labor cost, increase tax for raw materials.

APPENDIX Z: Structure Layer – Barriers and enablers coded

- BARRIERS

EXPERT	A	B	D	E	F	G	H	I	J	K	M	EVENTS	TOTAL
Finance & Economic	x	x				x	x	x		x	x	7	11
Lack of Maintenance & Performance Services	x		x	x	x							4	11
Part of the Structure	x				x					x		3	11
Products, Components and Materials of the Layer			x			x	x	x	x	x		6	11
Legislation & Policy		x				x						2	11

- ENABLERS

EXPERT	C	D	E	G	I	J	K	L	M	EVENTS	TOTAL
Implementation of PSS for Temporary Structures				x	x	x			x	4	9
Definition of Services for the Layer	x			x		x			x	4	9
Design & Engineering		x	x	x	x		x	x		6	9
Technology				x						1	9

APPENDIX AA: Skin Layer – Barriers and enablers coded

- BARRIERS

EXPERT	B	D	E	G	J	K	L	M	EVENTS	TOTAL
Finance & Economic	x	x	x	x	x	x	x	x	8	8
Legislation & Policy	x		x	x	x	x	x	x	7	8
Knowledge & Culture			x	x	x				3	8

- ENABLERS

EXPERT	B	C	D	E	G	J	K	L	M	EVENTS	TOTAL
Definition of Service and Performance Element for the Layer		x	x		x	x			x	5	9
Finance & Economic			x	x	x	x	x	x		6	9
Knowledge &Culture			x		x	x				3	9
Policy & Legislation	x				x	x	x	x	x	6	9
Design & Engineering						x				1	9
Supply Chain			x			x				2	9
Technology					x	x	x			3	9

APPENDIX BB: Services Layer – Barriers and enablers coded

- BARRIERS

EXPERT	B	D	G	H	EVENTS	TOTAL
Finance & Economic			x	x	2	4
Knowledge & Culture	x		x		2	4
Legislation & Policy		x			1	4

- ENABLERS

EXPERT	A	B	C	D	E	G	H	I	M	EVENTS	TOTAL
Technology							x			1	9
Design & Engineering	x	x	x	x	x	x	x	x		8	9
Finance & Economic		x				x	x	x		4	9
Definition of Service and Performance for the Layer			x						x	2	9

APPENDIX CC: Opportunities for the company coded

	Expert Code	A	B	C	D	E	F	G	H	I	J	K	L	M	EVENTS	TOTAL
SUPPLY CHAIN	Less logistics											x	x		2	13
	Less time											x	x		2	13
FINANCE & ECONOMIC	Reduced impact of financial cycles							x	x						2	13
	Reduced impact of real estate cycles							x	x						2	13
	Branding recognition							x							1	13
	Long term cash flow						x								1	13
	Stable cash flow						x								1	13
	Strong relationship with client					x									1	13
	Higher profit				x	x		x	x				x		5	13
	Receive Subsidize										x	x	x		3	13
	Managing PCMs during their lifetime	x	x	x		x		x	x	x	x				8	13
TECHNOLOGY	Keep trak of PCMs	x	x								x				3	13
	Access to data	x		x	x	x			x		x				6	13
	Incentivize innovation	x	x		x			x			x				5	13
DESIGN	Incentivize quality		x	x			x	x			x	x	x		7	13
ENVIRONMENT	Sustainability	x				x									2	13
	Resource efficiency							x			x	x	x		4	13
	Reduced environmental impact				x		x				x	x	x		5	13
	Low CO2 emissions				x							x	x		3	13
	Less raw material					x		x							2	13
	Dematerialization											x	x		2	13
POLICY & LEGISLATION	Comply with Transition Agenda 2050					x									1	13
	Comply with the environmental impact index of Bouwbesluit					x		x							2	13

APPENDIX DD: Opportunities for the client coded

Expert Code	A	B	C	D	E	F	G	H	I	J	K	L	M	EVENTS	TOTAL
No burden of ownership	x	x	x		x		x	x	x	x				8	13
Higher quality PCMs		x	x			x	x			x	x	x		7	13
Low initial investment				x	x									2	13
Predictable exploitation cost	x			x										2	13
No logistics for PCMs					x									1	13
Convenient arrangement						x	x	x						3	13
Sustainable solution	x								x	x				5	13
Higher customization					x									1	13
Involve the client in the decision making process									x	x				2	13

APPENDIX EE: General Barriers coded

	Expert Code	A	B	C	D	E	F	G	H	I	J	K	L	M	EVENTS	TOTAL
FINANCE & ECONOMIC	Financing	x	x		x			x	x	x				x	7	13
	Cash flow issues	x	x		x			x		x		x	x		7	13
	Lack of proof of concept	x										x		x	3	13
	Underdeveloped marketplace for secondary PCMs	x						x		x				x	4	13
	Lack of valuation methods for reused PCMs	x								x		x		x	4	13
	CE used as a marketing tool	x			x			x			x				4	13
	High initial upfront investment				x	x		x							3	13
	Conservative financial parties				x	x						x	x		4	13
	Expensive for client					x									1	13
	Cost of transition							x			x	x	x		4	13
	Low price of raw material							x						x	2	13
	Lack of information regarding current real estate expenses							x							1	13
	Type of company										x				1	13
	High cost of labour										x			x	2	13
	Retaining close relationship with large client base		x												1	13
DESIGN	Complexity of the building		x												1	13
	Design for EoL				x	x			x			x			4	13
	Uncertainty regarding the quality of PCMs										x	x		x	3	13
	Constraints personalization									x					1	13
SUPPLY CHAIN	Conservative supply chain		x		x	x					x				4	13
	Logistics					x					x	x	x		4	13
	Fragmented supply chain							x							1	13
KNOWLEDGE & CULTURE	Idea that resources are infinite	x													1	13
	Transition period	x								x	x	x		x	5	13
	Conservative sector	x			x					x				x	4	13
	Operating in a linear economy		x		x			x			x	x			5	13
	Low importance of good contracting in the Netherlands				x										1	13
	Low importance of good maintenance in the Netherlands				x										1	13
	Ownership instead of usership mentality					x	x		x						3	13
	Lack of decision models							x							1	13
	Lack of accountability - interface problem							x							1	13
	Lack of awareness and interest									x	x				2	13
	Lack of knowledge										x			x	1	13
POLICY & LEGISLATION	Dutch property law		x		x			x			x			x	5	13
	Contracting						x							x	2	13
	Bouwbesluit					x				x		x	x		3	13
	Inadequate policy support	x					x			x	x	x	x		3	13
	Lack of tax incentives										x				1	13
	Lack of circularity indicators									x					1	13
	Lack of subsidize					x									1	13

APPENDIX FF: General Enablers coded

	Expert Code	A	B	C	D	E	F	G	H	I	J	K	L	M	EVENTS	TOTAL
FINANCE & ECONOMIC	Increase of PCMs residual value	x		x											2	13
	Proof of concept		x												1	13
	Development of new insurance products		x												1	13
	Optimization of the total cost of ownership			x	x					x					3	13
	Creation of an attractive investment opportunity				x										1	13
	Provision of guarantees				x										1	13
	Establishment of new companies focusing on financing				x			x							2	13
	Nurture the relationship with customer					x									1	13
	Risk distribution						x								1	13
	Equal profit distribution						x			x					2	13
	Engineer competitive business model				x		x	x		x	x	x	x		7	13
	Gathering of information regarding real estate expenses							x							1	13
	Valuation methods for PCMs at EoL					x					x	x	x		4	13
	Collective business model	x					x			x					3	13
	Demand financing from partners										x				1	13
SUPPLY CHAIN	Reverse logistics										x				1	13
	Storage deployment						x								1	13
	Collaboration in the supply chain						x			x	x				3	13
	Demand circular solutions from partners		x					x			x	x	x		5	13
	Mass material						x				x				2	13
DESIGN	Design for reuse				x										1	13
	Easy repair and update	x				x	x		x	x	x				6	13
	Modular design	x	x			x		x	x		x	x			7	13
	Prefabrication				x			x							1	13
	Standardization				x							x			2	13
	Engineer PCMs with materials for CE				x	x					x				3	13
	Design for disassembly					x					x	x			3	13
	Design for adaptability & flexibility					x									1	13
	Quality check of PCMs at EoL							x			x	x			3	13
	Include customer in the design									x					1	13
	Design for attachment									x	x				2	13
	Design for failure										x				1	13
	Creation of PCMs on demand										x				1	13
	Design for durability		x	x			x				x	x	x		6	13
	Service and performance element	x		x	x	x					x			x	6	13
	Design for sustainability									x					1	13
	Definition for which PCMs the PSS CBM is applicable													x	1	13
TECHNOLOGY	Digital twins & Information systems (BIM)	x				x		x	x		x				5	13
	Database for buildings PCMs (Material Passports)	x	x			x						x	x	x	6	13
	Keep function at high level of performance			x											1	13
	Platforms for secondary material	x						x		x	x			x	5	13
	3D printing										x				1	13
	Technology and complexity element	x	x	x	x	x			x						6	13
KNOWLEDGE & CULTURE	Systems thinking and systems change	x					x								2	13
	Inclusion of new generations in decision making processes	x													1	13
	Trust		x		x						x				3	13
	Increase awareness and interest		x				x	x	x						4	13
	Increase knowledge				x		x				x	x			4	13
	Experimentation for the transition					x		x			x	x			4	13
	Staff training and education					x									1	13
	Political willingness to go through the transition period							x			x	x	x	x	5	13
	Development of a good flow of knowledge in the company										x				1	13
	Be a frontrunner										x				1	13
	Definition for which PCMs the PSS CBM is applicable													x	1	13
	Knowledge sharing	x									x				2	13
POLICY & LEGISLATION	Tax incentives	x							x	x	x	x	x	x	7	13
	Policy support	x					x					x	x		4	13
	Procurement incentives		x												1	13
	Change the Dutch property law		x		x			x			x	x		x	6	13
	Subsidize					x		x		x	x				4	13
	Contracts for PSS & CE	x				x	x	x				x			5	13
	Change public comissioning		x					x							2	13
	Change Bouwbesluit					x	x				x	x	x		5	13
	Lobbying										x				1	13