Transforming the Built Environment through Product Service Systems: A Path towards a Circular Economy

"Exploring the Key Characteristics, Challenges, and Solutions in Implementing PSS in the Built Environment"

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Abstract

As climate change and resource shortages increasingly threaten our planet, the built environment sector is under scrutiny due to its significant contribution to carbon emissions and global raw resource extraction. A transition towards a circular economy, replacing the prevailing "take-make-dispose" model, is crucial. This research explores the concept of Product-Service Systems (PSS) in the built environment, wherein products are provided as services, thereby increasing supplier responsibility and closing the resource loop.

This study answers the research question: "How can Product-Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?" It delves into the various characteristics and properties of products within PSS and factors influencing these systems. Furthermore, it analyses the roles of different stakeholders within the circular chain of PSS, current implementation of PSS in the built environment, and future possibilities.

Adopting a qualitative research method, the study begins with an extensive literature review to provide an overview of current concepts and existing PSS models. This review forms a basis for identifying critical properties and characteristics necessary for successful PSS implementation. In-depth interviews with experts further provide insights into potential new opportunities for PSS in the built environment.

The research highlights the modularity, environmental sustainability, and economic viability of various building products, ranging from windows and doors to smart building technologies. A comprehensive table analysis reveals the potential for PSS implementation and the degree of circularity for these products. This research contributes to the field by presenting new possibilities for expanding PSS in the built environment. It emphasizes the need for pilot projects to better match practice with literature, increase the understanding of individual products, and uncover currently unknown factors. By enhancing our knowledge of PSS, this study propels us one step closer to achieving a circular economy in the built environment.

Keywords

Circularity, transition to circular Economy, Product Service System (PSS), resource efficiency, building technologies, waste reduction, Built Environment, leasing, circular supply chain, Sustainability, modularity, resource management, stakeholder engagement,

Executive Summary

The built environment represents a significant area for the implementation of sustainable practices, particularly the application of PSS. This research aimed to explore how PSS can be applied in the built environment and expanded to their fullest potential, paving the way for a circular economy that values sustainability and resilience.

The research identified several internal and external factors that influence the effective implementation of PSS, including the legal environment, contract structure, financial models, incentives for producers, risk mitigation strategies, and the importance of collaboration among stakeholders. It emphasized the need for a good business model, the involvement of financial institutions, and the provision of convenience for clients.

Further, the research detailed the essential properties and characteristics for the optimal functioning of PSS, such as durability, repairability, (re-)usability, customizability/standardization, modularity, environmental sustainability, and economic viability. It suggested a multi-step approach: firstly, understanding these key factors, properties and characteristics; secondly, selecting products based on these identified characteristics for a PSS model; and thirdly, addressing the readiness of companies and their stakeholders to integrate PSS into their business operations.

A close examination of product service systems in practice from various sectors, provided valuable insights into the practical aspects of implementing PSS. These systems highlighted the existing gaps in logistics, the need for increased awareness of the circular economy among stakeholders, and the potential role of government in mandating CE regulations. The research suggested that companies should initially focus on establishing a financially viable PSS before shifting their focus to circularity.

The research concluded that the application of PSS in the built environment has significant potential to transform the sector into one that aligns with the principles of the circular economy. However, realizing this potential requires concerted efforts from all stakeholders to overcome the identified barriers. A society without ownership is within reach, but the journey to it necessitates collaboration, awareness, and a shift in focus from ownership to service.

In summary, this master thesis provides a comprehensive exploration of PSS in the built environment. It presents an actionable roadmap for companies, policymakers, and other stakeholders, offering insights into the challenges and solutions associated with the adoption of PSS. By advocating PSS, all stakeholders can contribute to a sustainable and thriving future, making the built environment a model sector for the circular economy.

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Abbreviations

BE = Building environment

CE = Circular Economy

BM = Business model

PSS = Product service systems

LCA = Life cycle assessment

Important translations

Onroerend goed = Immovable property

Roerend goed = movable property

Natrekking = accession

Opstalrecht = right of superficies, superficies

Eigendoms recht = right of ownership , proprietary right , ownership right , property right , property ownership

Een werk = “works”

Eenheidsbeginsel = Principle of unity, unity principle

Verkeersopvatting = public opinion, common opinion, general prevailing opinion

Conservatoir beslag = prejudgment attachment, attachment before judgment, conservatory attachment

CHAPTER 1

INTRODUCTION

CHAPTER 1: Introduction

1.1 Research context and problem statement

The world is undergoing a rapid transformation, with climate change and resource scarcity becoming more and more urgent issues. The growing population and increasing urbanization and prosperity are driving up the demand for energy, water, and resources (United Nations, 2023). However, Earth's resources are finite, therefor new options are needed, such as the exploration of innovative solutions. One of these is the adoption of a circular economy, the goal of a circular economy is to strive towards resource efficiency, reduce waste and encourage sustainable use of the resources throughout their life cycles (EMF, 2015). The circular economy aims to build a more durable and sustainable system that helps both the environment and the economy by emphasising circularity.

The built environment is significantly impacted by these changes. The limited resource availability, coupled with the built environments substantial contribution to the carbon emissions and the global resource extraction (Copper8, 2020), demands a shift towards more sustainable practices. As an alternative, the circular model emphasizes minimizing waste, maximizing resource utilization, and creating a closed-loop system where resources are used, recovered, and regenerated continually. One potential circular solution lies in the implementation of Product-Service Systems (PSS) within the built environment, encouraging the transition from a linear "take-make-dispose" model to a more circular, resource-efficient model (EMF, 2013a).

This study is dedicated to exploring the potential of PSS within the built environment in the Netherlands. Our guiding research question is: “How can Product-Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?” By answering this question, we hope to shed light on the possibilities, challenges, and implications of implementing PSS in this sector.

There are already examples of PSS implementation in the built environment, including Philips' "pay per lux" lighting systems (Philips, 2021) and Mitsubishi's lift rentals (Mitsubishi, n.d.). Furthermore, larger-scale initiatives, such as TU Delft's façade-as-a-service pilot project, demonstrate the potential for PSS to be applied to various building components (Azcárate-Aguerre et al., 2017). However, the adoption of such a model within the built environment is riddled with challenges, necessitating novel business models such as PSS.

PSS presents an innovative approach, transitioning from the traditional concept of ownership towards a system of access, use, or performance-based agreements (Ploeger et al., 2019). While promising, the transition to PSS is not without complexities. The unique characteristics of the built environment, such as long life spans, numerous stakeholders, and diverse building components, amplify these challenges (Hart et al., 2019). Moreover, the legal and regulatory environment, especially within the context of Dutch property law, presents potential difficulties for PSS implementation (van de Griendt, 2018).

Stakeholders play a fundamental role in facilitating the successful implementation of PSS. From producers to users, and government parties, each stakeholder group's involvement can drive the shift towards a more circular economy. However, multiple factors, including Dutch law, contracts, producer incentives, risks, and the collaboration of stakeholders, can influence the implementation and success of PSS in the built environment.

Looking forward, the future potential of PSS in the built environment is vast yet complex. The integration of PSS into various building components could significantly propel the sector towards enhanced circularity and sustainability. However, the feasibility and success of PSS hinge not only on a myriad of factors but also on the meticulous evaluation of a product's distinctive characteristics and properties. These can include durability, repairability, reusability, the balance between customization and standardization, modularity, environmental sustainability, and economic viability.

By investigating these aspects, this research aims to contribute to the understanding of PSS's potential and challenges in the built environment. The successful implementation of PSS in the built environment requires a thorough understanding of the unique characteristics, properties, and challenges associated with each PSS. The legal, financial, and collaborative aspects of PSS must be carefully navigated to ensure the transition to a more circular, sustainable built environment. This research aims to identify the essential characteristics, properties and factors for successful PSS implementation in the built environment and explore new possibilities for future PSS applications, contributing to the ongoing efforts to create a more sustainable world.

1.2 Research output

1.2.1 Research objective and goal

Since the linear economy is not sustainable forever, there is an increasing focus on a circular economy. This research will investigate product service systems in the built environment as a solution to create a more circular economy. The goal is to maximize products as a service in the built environment as much as possible. This research looks at how widely the model has been applied thus far and what all the new possibilities are. The characteristics and properties needed to become a successful PSS will be reviewed together with all factors that have influence on a PSS.

This research will give new possibilities for future PSS in the built environment and all characteristics, properties and factors needed to make this possible.

1.2.2 Deliverables

An overview of all deliverables is provided in Figure 1.1, with the deliverables divided over five significant milestones from P1 to P5. P1, which was delivered in October, encapsulated the problem statement, research objective, research questions, and the relevance of this research. Following this, P2 was the second milestone, delivered in January, encompassing the research method and the initial segment of the literature study.

The third milestone, P3, was completed in March and included the remaining part of the literature study, focusing on creating an overview of all aspects that influence PSS and including a research of existing PSS. Along with this, an analysis and list of properties and characteristics for PSS in the BE were also delivered. In addition to these, P3 involved the delivery of the interview protocol and the resulting datasets from these interviews.

The fourth milestone, P4, was achieved in May, which incorporated the comprehensive analysis of all interviews. It also included a conclusion, reflection, and discussion on the findings. The final milestone, P5, is scheduled for June. This will comprise the end report, tailored for the TU Delft repository, and a presentation where the research findings and results will be discussed. As of now, all milestones up to P4 have been successfully completed and delivered, with P5 remaining as the next step.

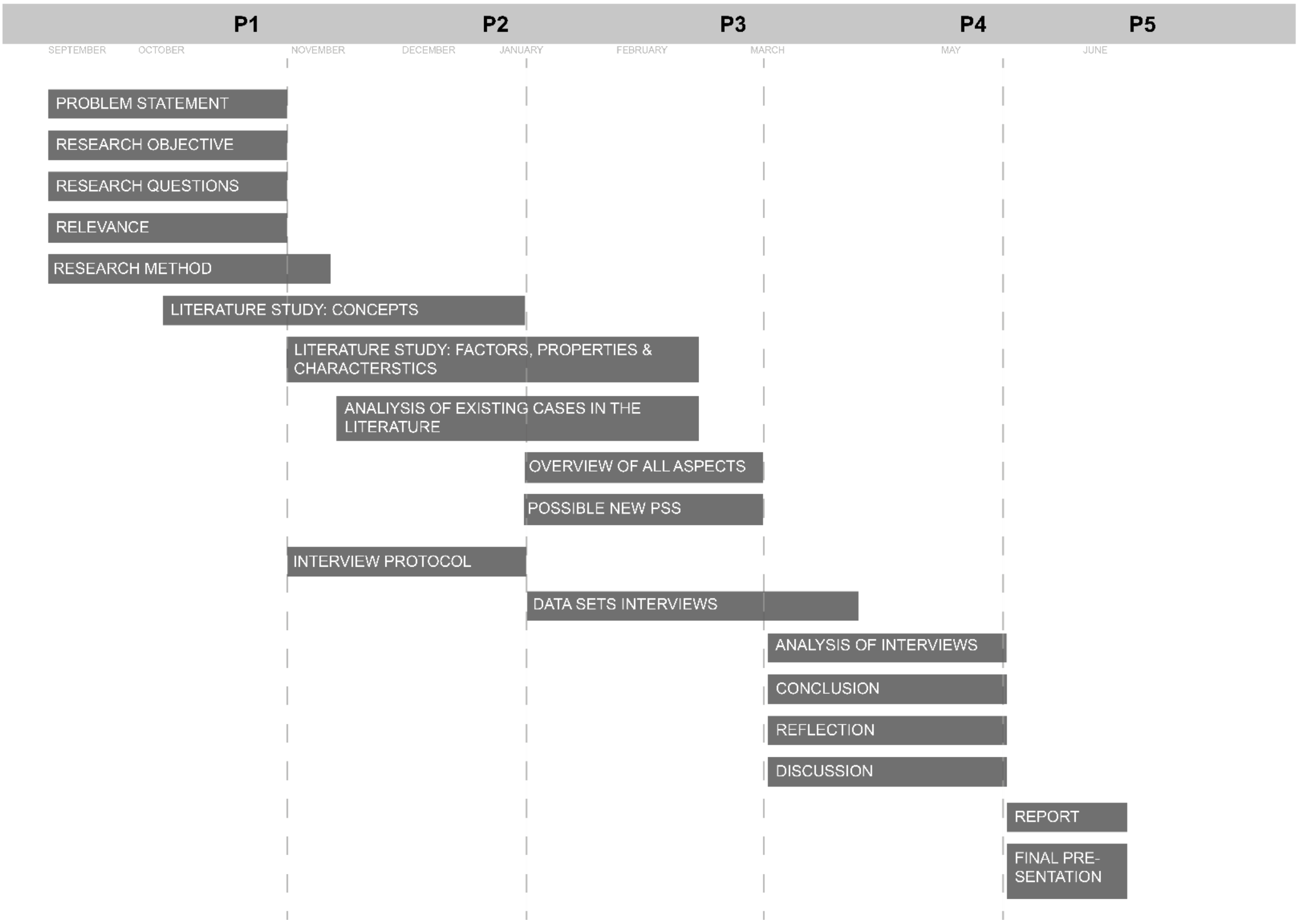

Figure 1.1: Deliverables of the research (own figure)

1.2.3 Dissemination and Audiences

This research is targeted at academics and businesses interested in exploring the potential of the circular economy in the built environment through innovative approaches. The study investigates the possibilities of PSS and how they can be expanded within the built environment. The results of this research offer new opportunities for future PSS development and reveal characteristics and properties necessary for products to be effectively used as services. Various businesses can benefit from the knowledge gained in this study, using it to create new PSS.

Additionally, this research is relevant to governmental parties responsible for regulating the BE. Alongside the opportunities it presents, the study also identifies limitations imposed by current regulations that may hinder the implementation of certain PSS. By utilizing this research, governmental parties can better understand how to create an appropriate regulatory environment to support the transition to a circular economy, which aligns with the Dutch government's goal for 2050 (Ministerie van Infrastructuur en Waterstaat, 2022).

In summary, this research provides valuable insights into the use of PSS and their potential contribution to a more circular economy. Thus, it is of interest to all parties committed to fostering a more circular built environment.

1.3 Research Questions

To achieve the research objective the following research question is formulated:

How can Product-Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?

In order to answer this research question the following sub questions are formulated. These questions will be answered throughout this thesis.

SQ1: What is circularity in the built environment?

SQ2: What are product service systems in the built environment?

SQ3: What is the importance of the stakeholders within the circular chain of product service systems?

SQ4: What factors influence product service systems?

SQ5: What are the characteristics & properties necessary for product service systems?

SQ6: What are the future possibilities for product service systems in the built environment?

1.4 Relevance

Societal relevance

The global demand for raw materials is rising. In order to use raw materials more wisely and cheaply, the government is collaborating with a lot of different parties. The Dutch government set a target for the Netherlands to have a fully circular economy by 2050 (Ministerie van Infrastructuur en Waterstaat, 2022). To achieve this goal there is still a long way to go, the built environment is a rigid business. In this research using products as a service in the BE is investigated. This might be a solution for the BE to become circular, However there are still many difficulties to overcome. In this research the "how" will be investigated. How can we use PSSs in practice and what exactly is needed to make this possible, such as different contracts, regulations, properties and characteristics.

Scientific relevance

Circularity is discussed a lot in the literature, but still there needs to be a lot more achieved in practise, especially in the BE. Hart et al. (2019) describes barriers and drivers in the circular economy for the built environment. Also in the master thesis of Kuipers (2019) barriers and enablers for product as a service are described. Both of these researches describe that for further research practise should be connected. *"Future work will test this analysis and define what is required to put the enablers into practice and accelerate uptake of CE in the built environment." (hart et al., 2019).*

In this research the goal is to create new possibilities that could be used in practise. This research will take information from the literature, such as important factors and concepts related to PSS, and connect these to new PSSs. Research from Ploeger et al. (2019) and van de van de Griendt (2018) will be used as ground work for different possible contract models and connected to new products that might work with these models.

1.5 Personal study targets

Circularity is the future, since our planet's resources are not inexhaustible. The burden is on us, as humans, to devise innovative ways to adopt a more circular approach and minimize resource wastage. Aligning with this perspective, the Dutch government aims for the Netherlands to become fully circular by 2050. However, transformations within the built environment, known for its complexity, are not straightforward. Often, developers perceive circularity as an expensive alternative. In my research, I intend to explore options beyond mere recycling, delving into the realm of PSS. I aim to investigate the potential of PSS and contemplate whether leasing, instead of owning products, might indeed represent the future.

1.6 Thesis outline

In figure 2 an overview is given of the possible thesis outline of the whole thesis end report.

	Chapter	Content
1.	Introduction	The introduction covers a wide range of subjects. It analyses the thesis's social and scientific elevation in addition to its topic and problem description. It also describes the research objectives and personal research goals.
2.	Explanation of circularity and concepts	This chapter introduces key concepts of circularity, setting the stage for the initial part of this thesis. It offers an overview of linear and circular models, their impacts on the built environment, and the role of circular supply chains. Special emphasis is placed on PSS as mechanisms for a circular economy and the importance of stakeholder collaboration in this transition.
3.	Research Method	This chapter details the methodology used to explore PSS implementation in the built environment. The approach involves a literature review to identify PSS influencing factors and properties, an examination of existing PSS practices, and the development of a comprehensive inventory for effective PSS implementation.
4.	Factors that influence PSS	This chapter explores key factors influencing the establishment and operation of PSS in various industries. Crucial aspects include regulations and laws, which can impact product suitability for PSS and the type of contracts employed. Incentives for producers also play a significant role in PSS adoption, requiring either intrinsic motivation or financial stimulation. Additionally, the chapter considers risks faced by stakeholders, such as high investments, design and policy challenges, and ownership issues. This comprehensive understanding provides valuable insights for developing effective PSS implementation strategies.
5.	Characteristics & properties	This chapter delves into the essential properties and characteristics, such as durability, repairability, (re-)usability, customizability, modularity, environmental sustainability, and economic viability, that determine the effectiveness and success of PSS.
6.	Product selection	This chapter focuses on identifying potential products suitable for PSS based on the established characteristics and properties discussed in previous sections. A comprehensive overview of these characteristics, as derived from literature, is provided in a figure, serving as a guide for product selection. The aim is to streamline the process of product identification for PSS, ensuring that the chosen products align with the crucial properties required for successful PSS implementation.
7.	Empirical research	This chapter presents the findings from semi-structured, in-depth interviews with industry professionals, further investigating insights from the literature review.
8.	Discussion	This chapter delves into critical areas of the research, highlighting potential avenues for further exploration and future studies. It discusses the complexity of implementing PSS in the built environment, involving factors like product characteristics, regulatory frameworks, stakeholder engagement, and market acceptance.
9.	Conclusion	This concluding chapter synthesizes the findings of the study which explored the application of PSS in the built environment in the Netherlands, with an emphasis on their potential to promote circularity and sustainability.
10	Reflection	Reflection of the graduation process will be given in this chapter.
11	References	All literature used within this research

Figure 1.2: Overall thesis outline (own figure)

CHAPTER 2

Explanation of circularity and concepts

Chapter 2: Explanation of circularity and concepts

This chapter serves as an introduction to the various concepts of circularity and provides the groundwork for understanding the context of the first part of this master thesis. The aim is to present a comprehensive overview of the linear and circular models, their implications on the built environment, the role of circular supply chains, and the significance of Product Service Systems (PSS) in promoting a more circular economy. Additionally, the importance of stakeholders and their collaboration in developing a circular economy will be discussed.

2.1 The Linear model

The linear model is a well-known economic theory that bases resource use on the "take, make, use, dispose" principle (EMF, 2013a). The linear model depicts the extraction of raw resources from the environment, their transformation into goods, usage by consumers, and eventual disposal as waste. Due to the fact that it travels in a straight line from extraction to disposal, this model is frequently referred to as "linear" (Elisha, 2020). The industrial economy has not moved from this linear concept. Companies extract materials, apply energy and labour to manufacture a product and sell them the consumer, who discard the product is no longer needed (EMF, 2013a).

The 'take-make-dispose' model was based on past centuries of declining real resource prices, enabling advanced nations to build their economies. The current wasteful method of resource utilisation was also made possible by the low level of resource prices in comparison to labour costs. Given the ease of obtaining new input materials and the low cost of waste disposal, recycling materials has not been a top economic concern. Using more resources, such as energy, was even in one of the biggest economic gain to reduce labour costs. (EMF, 2013a) This resulted in a lot of waste of resources that cannot be easily refilled or repaired. The linear model in a shrinking world resulting in an unstable development in the global economy (Korhonen et al., 2018). Humanity is currently consuming more than the productivity of Earth's ecosystems can sustainably offer, and as a result, we are draining the planet's natural capital rather than just surviving off of it (EMF, 2013a). Resource scarcity, price squeezes and increasing volatility already show that the linear model is no longer (economically) feasible.

Recently companies started realising that the linear system increases the exposure to risks, but also higher resource prices (EMF, 2013a). The natural resources affect the economy by serving as sinks for outputs in the form of waste as well as inputs for production and consumption (Geissdoerfer et al., 2017).

2.2 Circular Economy/ model

The circular economy is an economic model aimed at reducing waste and maximizing resource utilization (EMF, 2013a). It seeks to keep resources in use for as long as possible, extract maximum value while in use, and recover and regenerate products and materials at the end of their service life (EMF, 2013a). This approach promotes the use of recycled materials and the reuse of products and resources, ultimately aiming to create a closed-loop system where materials are continually used and recovered instead of being discarded as waste (Stahel, 2016). Such a system can help reduce environmental impacts, increase resource efficiency and create economic opportunities (EMF, 2013a).

Korhonen et al. (2018) offer a comprehensive overview of the concepts and limitations of the circular economy, defining it as a system that maximizes the service provided by the linear flow of material and energy between nature, society, and nature through societal production consumption processes. This is achieved by leveraging cascading energy fluxes, renewable energy sources and cyclical material flows, while supporting all three pillars of sustainable development. Circular economies align economic cycles with ecosystem cycles by respecting their natural reproduction rates and limiting output flow to a level that nature can tolerate (Korhonen et al., 2018).

The circular economy emphasizes the need for a "functional service" approach, where manufacturers or retailers increasingly retain ownership of their products and act as service providers selling the use of products rather than their one-way consumption (EMF, 2013a). This shift can promote the development of more durable products, facilitate disassembly and refurbishing, and encourage the adoption of product/service transitions when appropriate (Ghisellini et al., 2016). Lewandowski (2016) emphasizes that new business models are crucial for achieving a circular economy. Also Kirchherr et al. (2017) argues that a more comprehensive understanding of these models is needed to facilitate the transition.

According to EMF (n.d.), the circular economy is based on three key principles: eliminate waste and pollution, circulate products and materials at their highest value, and regenerate nature. These principles translate into designing out waste, building resilience through diversity, relying on energy from renewable sources, thinking in systems, and viewing waste as a resource (EMF, 2013b). Circular Economy (2018) also emphasizes the importance of minimizing resource flows, closing loops, and transitioning to regenerative resources and clean energy.

The development of a circular economy begins with skills in circular product design (EMF, 2013a). Products should be designed for the future, using long-lasting materials, easy disassembly, standardization, and efficiency (Circle Economy, 2018). As Lewandowski (2016) and EMF (2013a) emphasize, new business models are essential for a circular economy, including performance contracts, treating consumers as users, and implementing PSS. Other crucial steps include constructing reverse cycles and cascades, enhancing performance across sectors and cycles, incorporating digital technologies, increasing transparency, and fostering collaboration throughout the supply chain with organizations and the public sector (EMF, 2013a; Circle Economy, 2019).

2.3 Circularity in the built environment

Circularity in the built environment entails planning and managing infrastructure, buildings, and other components in a way that maximizes resource utilization and minimizes waste. This can be achieved through various strategies, such as using sustainable materials and technology, designing for reusability and flexibility, and promoting resource-conserving behaviours (Geissdoerfer et al., 2017; EMF, 2013). Implementing a circular economy across numerous sectors offers significant benefits for the built environment, including reducing ecological and carbon footprints (Mhatre et al., 2021) and supporting economic growth (EMF, 2013).

Incorporating circular economy principles into the built environment contributes to the development of more liveable and resilient communities. As sustainability measures become increasingly mandatory due to government regulations, embracing circularity is an essential requirement for achieving sustainability in the built environment (Geissdoerfer et al., 2017). For instance, the Dutch government has set ambitious goals to become fully circular by 2050 (Ministerie van Infrastructuur en Waterstaat, 2022), demonstrating a commitment to integrating circular economy principles into the built environment and beyond.

Connecting this concept to the previously discussed circular economy principles, it is crucial to recognize that the built environment offers significant opportunities for implementing PSS, new business models, and collaborative strategies across supply chains. By emphasizing the need for circular design, resource efficiency, and waste reduction in the built environment, it becomes possible to create a more sustainable future that aligns with the overarching goals of the circular economy.

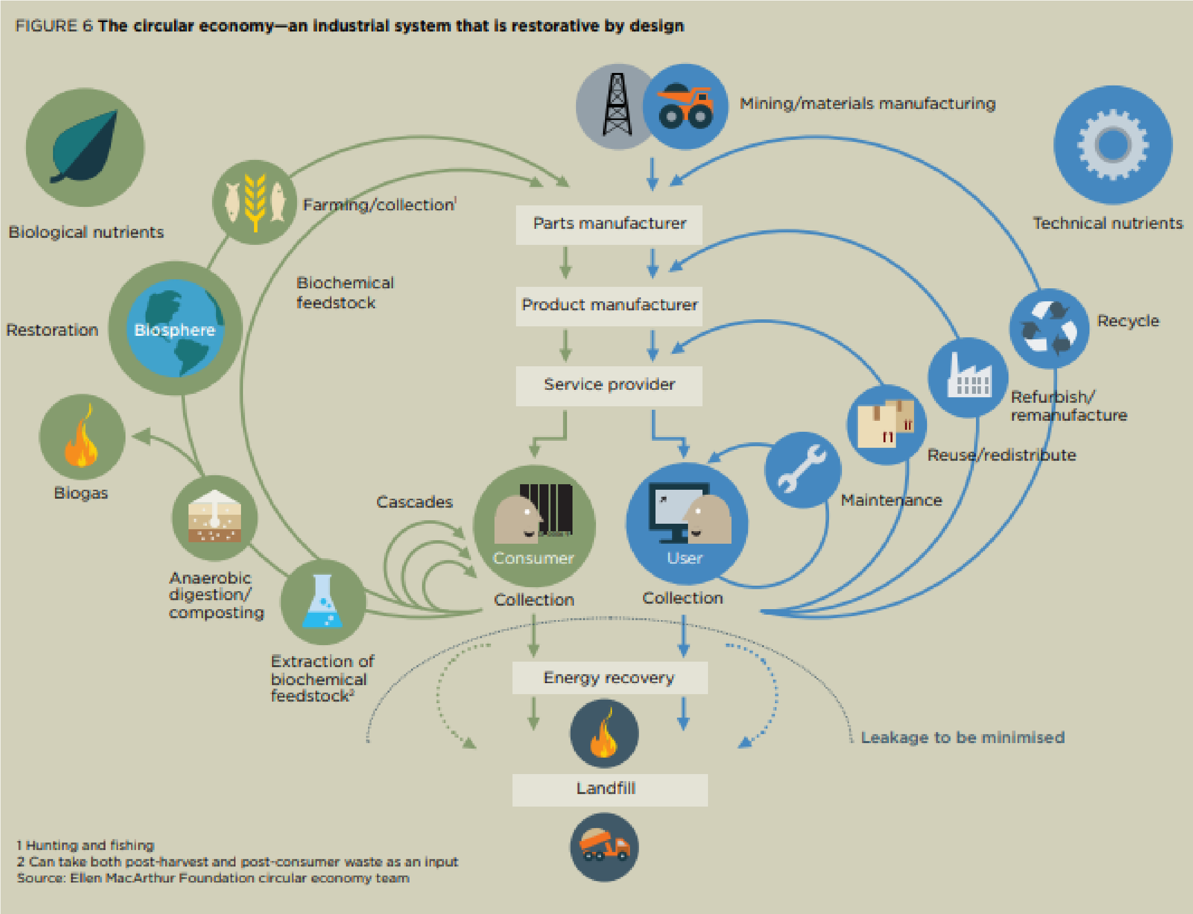

Figure 2.1: Circular Economy (Source: Ellen MacArthur Foundation, 2013a)

2.4 Circular supply chain

The goal of the circular economy is to maintain materials, components, and products throughout time in both biological and technical cycles at their optimum utility and value, as shown in figure 2.1. In order to improve natural capital, biological components or nutrients can be safely added back to the biosphere (Farooque et al., 2019). One key aspect to make this possible is the idea of closed-loop systems, where waste products and by-products are reused, recovered and recycled to extend the life of resources (EMF, 2013a). This can entail recovering and reusing resources on a broader scale by working with other organisations, or it can involve reusing materials or energy within a single building. A circular supply chain uses materials that can be renewed or recycled to make items that can be recycled, repaired, or refurbished. Products are recovered when their useful lives are finished, and the materials inside are then recycled or repurposed, completing the cycle of resource use (De Angelis et al., 2018).

There are some key principles that are important to guide the development within the circular supply chain:

- Products should be designed for circularity. By developing goods and services that satisfy the essential requirements of the circular business model, designers must alter their design thinking and interpretation of related behaviours that lead to the circular economy transition (Andrews, 2015). Products should be designed with reuse, repair, recycling in mind.
- The demand of resources needs to change. The traditional model needs to be combines with the reversable supply chain. Renewable and recycled materials should be used and sources made renewable whenever possible (Guide et al., 2003).

- Collaboration between the multiple stakeholders in the supply chain is key. The supply chain often requires a lot of long time collaboration between the different actors involved such as manufacturers, suppliers, customers and waste management organizations (Flink, 2017). In order to keep used goods, parts, and materials in use, there are many research opportunities in the fields of incentives and strategic value alignment (Genovese et al., 2017), collaboration and coordination mechanisms like contracts, supply chain integration, and knowledge management with suppliers, customers, and other stakeholders (Aminoff & Kettunen, 2016).
- New business models are needed to make the switch from a linear model to a circular model with closed loops. A business model is how an organisation generates, captures, and delivers value using a value creation logic intended to increase resource efficiency by extending the useful life of goods, parts and closing material loops (Nubholz, 2017).

Literature offers broader concepts of value creation within the circular economy such as: the power of "inner circle", "circling longer", "cascaded use and inbound material/ product substitution" and "pure, non-toxic, or at least easier-to-separate inputs and designs" (EMF, 2013a). Some end-of-life techniques, according to the power of the inner circle, produce more economic and environmental benefit than others. They preserve a product's embedded materials, energy, and labour to a far greater extent (Nasr & Thurston, 2006; EMF, 2013a). According to EMF (2013a) The following should be implemented in the end of life strategies: "Maintenance to increase durability; reuse for the same purpose; refurbishment and replacing and recovering relevant components; and lastly recovering of materials". Recycling is the least beneficial since this typically involves down-cycling, In figure 2.2 the flow of the different models is shown.

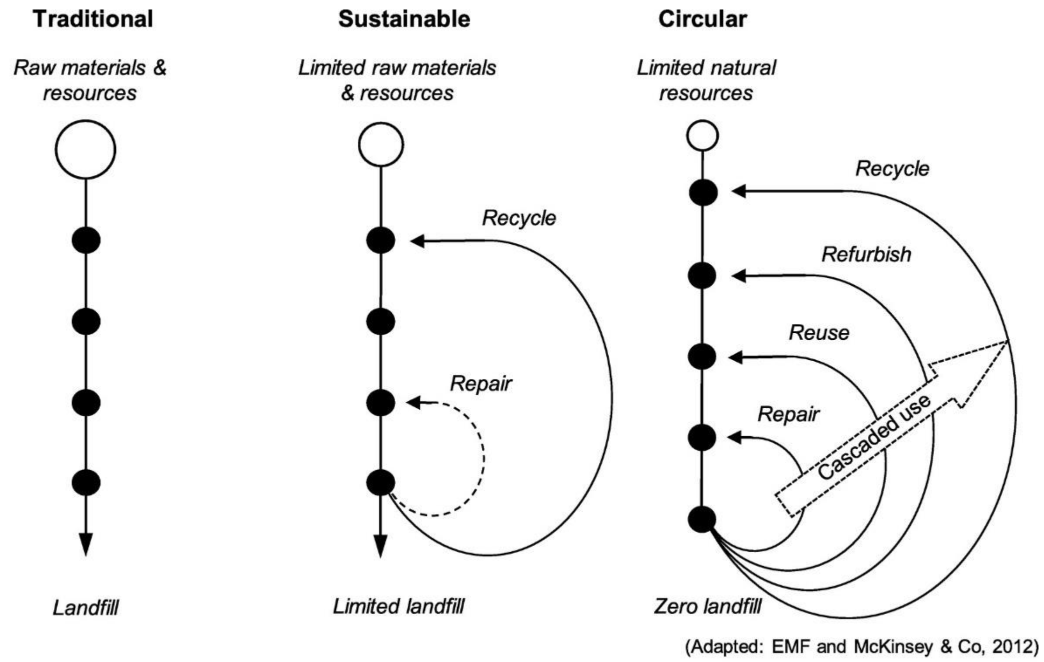

Figure 2.2: The different supply chains (De Angelis et al., 2018)

A circular supply chain seeks to reduce dependency on finite resources and the environmental effects of production and disposal in order to develop a more sustainable and effective system of production and consumption. A variety of tactics, such as design for circularity, closed-loop manufacturing processes, and cooperative relationships between businesses and other stakeholders, can be used to accomplish this. Overall, moving away from the conventional linear model of production and consumption, in which items are manufactured, used, and discarded, and towards a more sustainable and effective system of resource use, is represented by the circular supply chain.

2.5 Products as a service (PSS)

A Product Service System (PSS) is a model that integrates products and services to provide value to customers by fulfilling their needs, while simultaneously aiming to reduce environmental impacts and resource consumption (Tukker, 2004). By prioritizing functionality or desired outcomes instead of exclusively marketing tangible goods, PSS models prompt a transition from ownership towards access, use, or performance-based agreements (Mont, 2002). This innovative approach enables companies to explore new revenue streams, enhance customer relationships, and contribute to sustainability objectives (Baines et al., 2007).

Shifting towards a circular economy necessitates the restructuring of business models, supply chain structures, processes related to product/service design, manufacturing, consumption, waste management, reuse, and recycling (Hobson & Lynch, 2016). Linder et al. (2017) underscored the potential of circular business models, enabling a transition from product sales to leasing arrangements within the context of functional and secondary markets. In a PSS framework, companies offer products as services rather than outright selling the product. Thereby granting customers access to the product's advantages without requiring full ownership (Baines et al., 2017). Tukker and Tischner (2006) described PSS as a mix of tangible products and intangible services developed and combined to jointly fulfil customer needs, acknowledging the interdependency between products and services.

PSS promotes circularity by enabling product reuse and repurposing, reducing waste, and extending product lifecycles (Mont, 2002). However, a shift from ownership to services, such as leasing, may not necessarily result in environmental benefits unless consumer behaviour also changes accordingly (Junnila et al., 2018). Baines et al. (2007) identified key elements to define PSS: product (a tangible good fulfilling customer needs), service (a valuable service provided for a fee) and system (a group of components and their connections).

PSS can be categorized into three main types as seen in figure 2.3 (Demyttenaere et al., 2016; Tukker, 2004):

- Product-oriented PSS: Focused on selling a product and adding services that support it, including product-related services and advice or consultancy.
- Use-oriented PSS: The product is made available through rental or leasing contracts without transferring ownership. The supplier is responsible for product usage (e.g., leasing, renting, sharing).
- Result-oriented PSS: Focused on delivering a specific outcome or result, with the supplier agreeing to help the customer achieve it (e.g., pay-per-service, functional, activity management).

Within the built environment context, use-oriented PSS is particularly relevant, as products are supplied to customers without transferring ownership. Reim et al. (2015) suggested considering contracts, marketing, product and service design, sustainability, and networks when implementing use-oriented PSS. As the supplier's responsibility is high, it is crucial to develop comprehensive contracts outlining the levels of responsibility and terms of agreement.

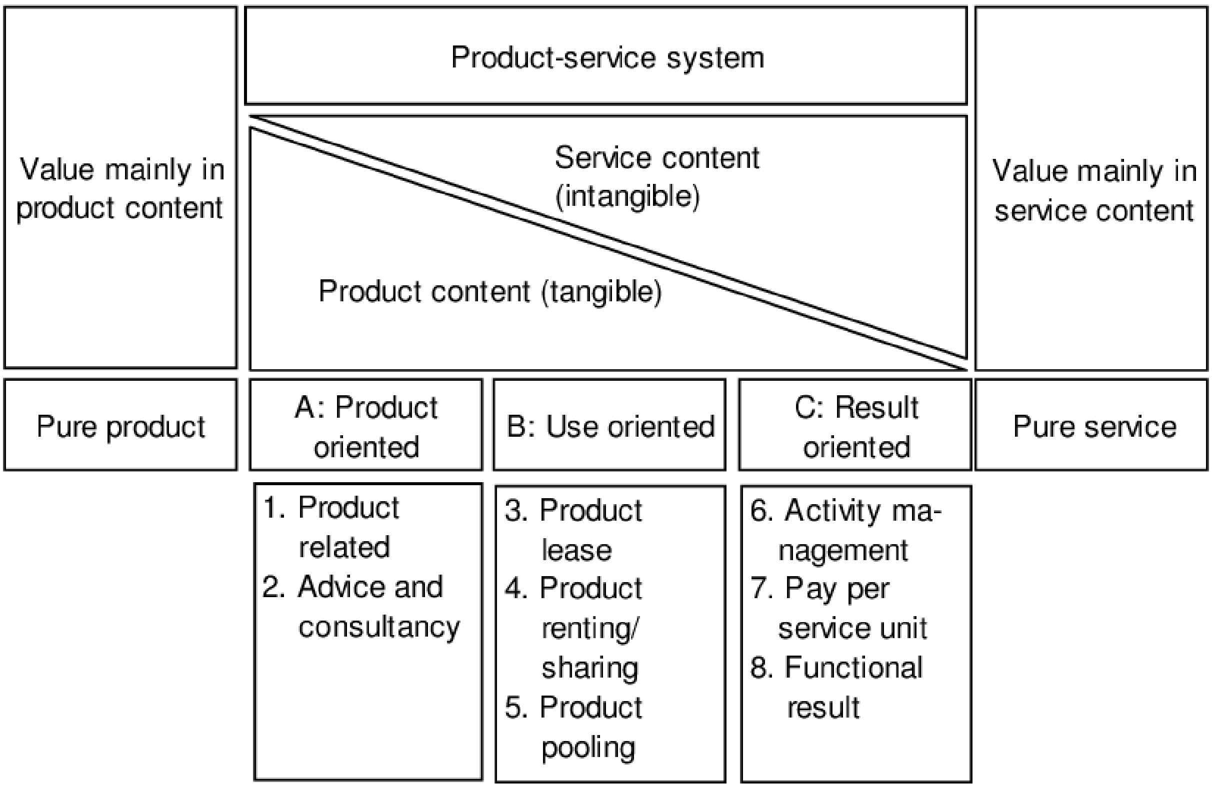

Figure 2.3: Main and subcategories of PSS (Tukker, 2004)

2.6 PSS Circular

Product Service Systems (PSS) do not inherently guarantee circularity or sustainability (Tukker & Tischner, 2006; Pieroni et al., 2019). Therefore, implementing PSS for a circular economy must be approached cautiously, as there is no assurance that it will reduce environmental impacts unless specifically designed to do so (Michelini et al., 2017). The Ellen MacArthur Foundation (EMF, n.d.) proposes three principles for a CE:

1. Eliminate waste and pollution
2. Circulate products and materials (at their highest value)
3. Regenerate nature

For a PSS to be circular, it must align with these principles. Only use- or result-oriented PSS types have the potential to increase natural capital through the management of finite stocks, thereby eliminating waste and pollution (Michelini et al., 2017). Michelini et al. (2017) argues that firms employing product-oriented strategies remain focused on increasing product sales, resulting in unrestricted resource utilization. The authors state that usage-oriented PSS may lead to less careful use, potentially having negative effects on resource and energy consumption, making circularity more challenging to achieve (Michelini et al., 2017; Tukker, 2015). The prospect of realizing circularity is greater in result-oriented PSS, where the producer retains ownership and is motivated to create a system with a lower impact on resource and energy efficiency.

Michelini et al. (2017) notes that companies transitioning towards more service-oriented PSS types, are incentivized to maintain products at their highest value and therefore enabling their reuse beyond the product's end of life. This approach optimizes resource yields through the circulation of products and components, facilitated by the businesses maintaining complete ownership.

However, PSS is not the only solution to addressing the environmental issues arising from the linear economy paradigm. As PSS is not inherently sustainable, there is no guarantee that it will reduce environmental impacts unless explicitly designed for that purpose. Consequently, life cycle assessment (LCA), which considers "cradle-to-cradle" material flow, is recognized as a crucial tool for designing product-service systems for the circular economy (Lieder & Rashid, 2016). LCA provides valuable insights into designing products for continuous recovery, ensuring that PSS models contribute to the realization of a circular economy.

2.7 Stakeholders

Stakeholders play an important role when it comes to the implementation of PSS in the built environment. Their involvement can significantly impact the project's success or failure. Suppliers, distributors, service partners, and branches that are actively interacting with customers and users while also connecting back to the provider make up the service delivery network (Parida et al., 2014). In addition, key stakeholders are the product's users (Mont, 2002). The service delivery network is even more crucial in high-value-adding PSS, where value is raised by co-creating the product (Parida et al., 2014). For a PSS deployment to be effective, it is essential to include many stakeholders. According to Seuring & Müller (2008), collaboration across the supply chain is essential for a building's full lifecycle and should involve all stakeholders, including those involved in design, raw material suppliers, end users, service providers, recyclers, and information flows.

In the context of a circular supply chain, stakeholders refer to individuals or groups that have an interest in or are affected by the activities and processes within the supply chain. Stakeholders in the circular supply chain can include:

2.7.1 The producers/ supplier

Suppliers will succeed when implanting CE by gaining access to new and larger profit margins, cutting material costs, overcoming several industry-level strategic difficulties, and increasing resilience as a consequence (EMF, 2013b). The role of the supplier is from only producer to the whole lifecycle of the product. The role of the supplier is extended outside of the traditional buyer-seller relationship (Mont, 2002). By taking on extra or deeper service duties, such as coordinating take-back plans, systems for reuse, remanufacturing, and recycling, and educating customers on effective product usage, the usual obligations for products are expanded. Reduced material flow necessitates closer supplier collaboration as well. It is simple to transfer knowledge and financial gains from the service provision stage to the manufacturing, development, and design stages. As a result, the entire system becomes more responsive to shifting market conditions and is likely naturally more likely to encourage innovation (Mont, 2002).

2.7.2 The user/ customer

If the PSSs are to be created and operated efficiently, the relationship between the business and the user of the product is crucial. Mont (2002) stated that some forward-thinking businesses have been collaborating more closely with their clients, who have since relied on them for a variety of information. When considering PSSs the costumer should be integrated in the development process as a "control device". The customer should be asked for their feedback early on in the process (Weber et al., 2004). In consequence, these businesses frequently have an early understanding of client interests, preferences, and local purchasing customs. As a result, these businesses are essential to both meeting and shaping customer preferences for products and services (Mont, 2002). According to EMF (2013b) states how more options, cheaper costs, and a reduced total cost of ownership can benefit customers.

2.7.3 Governmental parties

Governments play a significant role in shaping the policies and regulations that impact the circular supply chain, and they are therefore key stakeholders. As mentioned earlier property law has a big influence on the workings of PSS in the BE (Akkermans et al., 2008). There are some building components already functioning as a PSS, due to exceptions that are made (Azcárate-Aguerre et al. 2017; Azcárate-Aguerre et al., 2022). For future possibilities regulations should be changed, however changing regulations involves governmental parties and they are there for an important stakeholder within PSSs.

CHAPTER 3

RESEARCH METHOD

Chapter 3: Research method

This chapter outlines the methodology employed for this study. The research aims to explore the implementation of PSS within the built environment, focusing on the necessary factors, characteristics, and conditions for successful integration. Insights into the various concepts and functions of PSS have been provided in the preceding chapter.

The following research question is stated: *How can Product-Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?*

This chapter explains the research design and defines the methodology employed to address the research question. First significant factors that influence the PSS are identified by conducting a comprehensive literature review. Subsequently, various properties and characteristics are identified via an extensive literature analysis. Additionally, the examination of existing PSS implementations in practice will be undertaken, generating insights into the workings of a successful PSS. Eventually this will result into a comprehensive inventory of essential characteristics and properties required to develop an effective PSS in the built environment. The identified characteristics and properties will be used to pinpoint potential new PSS opportunities and strategies for successful implementation.

3.1 Research Design

In this research, a qualitative approach is used. Figure 3.1 illustrates the research design for this study. The research starts with a comprehensive review of literature on essential concepts and principles. The focus lies on understanding PSS, the circular economy, circular supply chains, and associated concepts. Additionally, a careful examination of influential factors such as contracts, liability, ownership, and Dutch law that might have an impact on PSS implementation is done. Also the product properties and characteristics that can influence the deployment of PSS is identified. Simultaneously, the research will delve into the examination of existing PSS case studies to collect critical insights in the factors, and characteristics that could be beneficially applied to the study.

Following these literature reviews and case study analyses, the accumulated knowledge will be used to compile a comprehensive list of the necessary factors and product properties for potential PSS application. This compilation will further aid in identifying new products that could be considered suitable candidates for PSS. The research will then extend to fieldwork, involving in-depth interviews

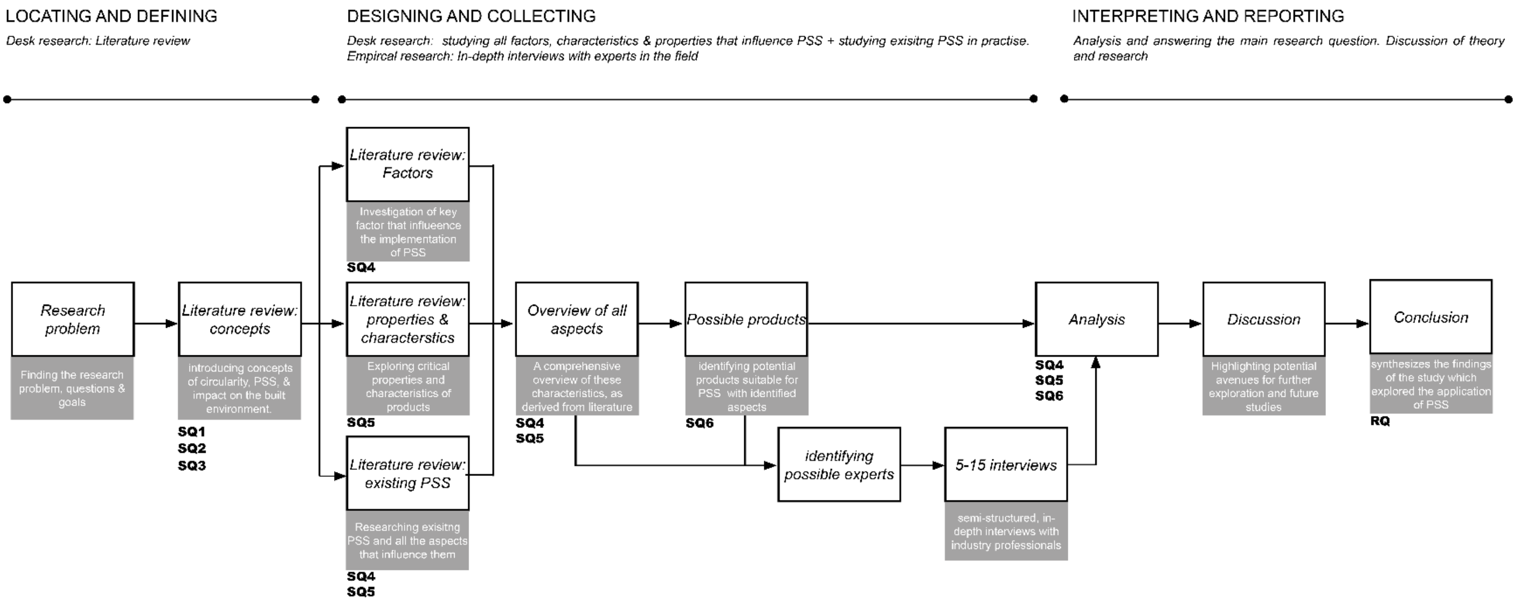

Figure 3.1: Research design and planning (Own figure, a bigger version is added to the Appendix VI)

with selected experts in the field. Theories, identified products, and potential PSS will be discussed during these interviews, soliciting expert perspectives on the subject matter.

The final stages of the research will involve data analysis, where the findings from the expert interviews will be synthesized to create a detailed description of the conditions necessary for making PSS possible. The project will conclude with an overall discussion and analysis of the research findings, acknowledging any limitations of the study and providing recommendations for realizing new PSS. The structure and flow of this research are visually represented in Figure 3.1.

3.2 Theoretical research

To conduct the literature study, the appropriate keywords were selected from the thesis's purpose and research questions. Various search results were obtained after performing a search operation. Articles were chosen from these search results based on the study area, the title, and the abstract; if it was pertinent, the entire paper was downloaded and read. Scopus, Google Scholar, and the TU Delft repository were the main search engines used in this research. Google Scholar is a generic search engine for scholarly papers with extensive coverage, and Scopus is a multidisciplinary information resource where you can conduct an article search. In TU Delft repository, the education and research repository was used, but student theses were also searched to find research from previous graduate students. In addition to using the search engines, this research also utilized snowballing methods. The term "snowballing" describes the process of finding more publications by analysing a paper's reference list or its citations (Wohlin, 2014). This is done to find new papers not found in the search engines and to create a better overview of the background used in papers.

In conducting this research, the study of literature is split into two distinct sections. The initial section primarily involves gathering background information and exploring relevant concepts critical to addressing the primary research question. The latter part delves into all factors, characteristics and properties that influence PSS. Also an analysis of existing PSS in literature is done. To answer the proposed questions, comprehensive desk research is undertaken.

3.2.1 Literature research

The first part of the literature review aims to provide a comprehensive understanding of the concepts and mechanisms of the circular economy, PSS, and the different stakeholders involved. And thereby establishing a strong theoretical basis for this research. To achieve this, a literature review is conducted, focusing on the first three sub-questions identified for this part of the research. To conduct this literature review, relevant keywords were entered into academic search engines. Different terms were used in combination to ensure a broad yet focused search of the literature. This systematic approach to literature review ensures that the analysis is comprehensive and provides a solid foundation for understanding the context of the first part of this research.

The first sub-question, "What is circularity in the built environment?" addresses the fundamental understanding of circularity and its role in the built environment. This is done through an extensive review of existing literature, predominantly focusing on works by the Ellen MacArthur Foundation (2013a), a leading source in the field of circular economy. The definitions and explanations from EMF (2013a) serve as a basis for this part of the review, supplemented by critical perspectives from Geissdoerfer et al. (2017) and Schut et al. (2015).

The second sub-question, "What are Product Service Systems in the built environment?" delves into the specifics of PSS and their practical applications. Literature dating back to 2004 is reviewed, with research from Tukker (2004) and Tukker & Tischner (2006) forming the basis for understanding PSS.

Other sources, such as Baines et al. (2017), who provide key elements to define products as a service for PSS, are also included in this part of the review.

The third sub-question, "What is the importance of the stakeholders within the circular chain of Product Service Systems?" addresses the roles of various stakeholders in the circular economy and their influence on PSS. The literature reviewed includes works by Flink (2017), Genovese et al. (2017), and Aminoff & Kettunen (2016), who emphasize the importance of collaboration among all parties involved in using a product as a service in the built environment. The review also includes Mont's (2002) analysis of the roles of suppliers and users, as well as the benefits they can derive from PSS.

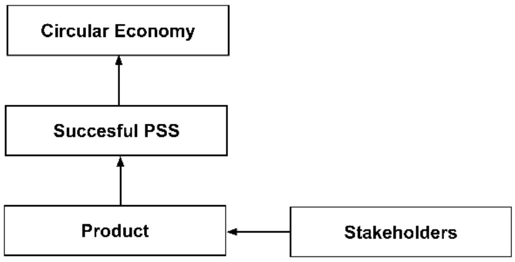

Figure 3.2: Basis of the conceptual model (own figure)

The second part of the literature review focuses on aspects that influence PSS, such as the factors, characteristics & properties. This will help answer the fourth and fifth sub questions: "What factors influence PSS?" & “What are the characteristics & properties necessary for PSS?”

First an in-depth exploration and critical analysis of the various internal and external factors impacting the establishment, operation, and effectiveness of PSS will be done. This research will review several key areas identified as significant factors that influence the PSS, including Dutch law and its legal concept, different contracts, incentives for producers, risks for stakeholders, and the collaboration of stakeholders. Works from prominent researchers in the field such as Ploeger et al. (2019), Mohammadi & Slob (2016), and Castelein (2018) serve as primary sources of information for this review.

In investigating the influence of Dutch law on PSS, the study leans heavily on the research by Ploeger et al. (2019), which delves into the role of Dutch property law in relation to PSS. This is further supplemented by the research of Akkermans & van Erp (2010) and also the thesis of van de Vondervoort (2019) that explores the broader scope of Dutch law and regulations. The exploration of legal concepts and their implications for PSS draws from the work of Demyttenaere et al. (2016), providing insights into different ownership factors within PSS. The research of Ploeger et al. (2019) also plays a significant role in this section, offering perspectives on different contract models and their benefits and limitations.

The factor risks for stakeholders combines research by Baines et al. (2007), Tukker (2015), Reim et al. (2015), and Kuijken et al. (2017). It explores risks such as high investments needed, challenges in return logistics, design complications, institutional and policy challenges, risks in ownership, and issues related to consumer awareness and interest. Each of these risk factors is discussed, supported by existing PSS and relevant research, including work from Kirchherr et al. (2017), Koukopoulou (2020), Kuipers (2021), Bocken et al. (2016), and EY (2022), among others.

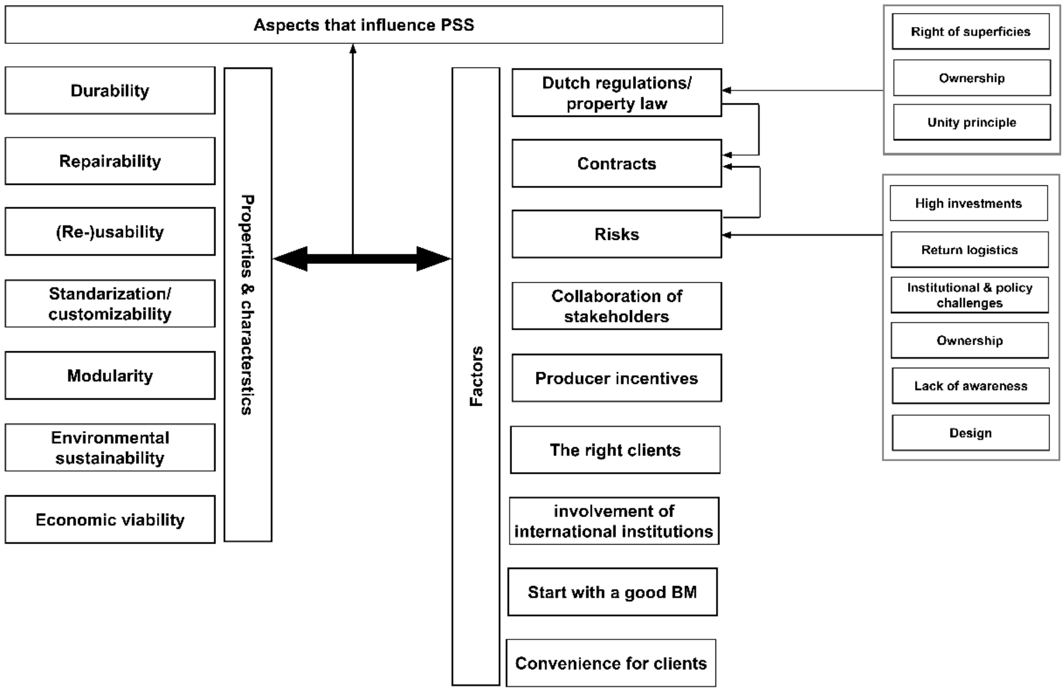

Figure 3.3: Second part of the conceptual model (own figure)

Followed is an investigation into the properties and characteristics inherent to PSS. These properties and characteristics include durability, repairability, (re-)usability, customizability/standardization, modularity, environmental sustainability, and economic viability. The literature review begins with a comprehensive exploration of the concepts of properties and characteristics, drawing on the work of Andreasen & McAloone (2008). This study establishes a clear distinction between these two aspects, defining properties as how a product behaves and characteristics as the composition and structure of a product that can be directly influenced by the designer.

The exploration of properties and characteristics begins with the property of durability in PSS, focusing on its impact on economic viability and environmental sustainability, guided by Yang et al. (2010) and Hieminga (2015). The significance of repairability is stated by research by Hieminga (2015), Tukker (2004), and Mont (2002), as well as the "power of inner circle" concept by the EMF (2013a). The critical roles of customizability and standardization are addressed next, informed by the work of Song & Sakao (2017), Ploeger et al. (2019), and Perera et al. (1999). The principle of modularity is subsequently explored, referencing Baldwin & Clark (2000) and Larsen et al. (2018). Tukker's (2015) research steers the investigation of environmental sustainability in PSS, followed by an analysis of its economic viability, drawing on insights from Tukker & Tischner (2006) and Baines et al. (2009).

The relationship between factors influencing PSS and the properties and characteristics inherent to PSS is intricate and multifaceted, providing a basis for further investigation. The interplay between these two aspects is crucial to understanding the overall PSS framework, as each property or characteristic of a product or service may be influenced by one or more factors, and vice versa. In figure 3.3 this is indicated with an arrow pointing both ways.

Specifically, this research will examine how each factor influences a given property or characteristic. For each property and characteristic in figure 3.3 the relations with the factors will be analysed. The results of this analysis will provide a comprehensive view of the relationships between the factors and the properties/characteristics. This will help illuminate potential interactions, conflicts, and gaps that can inform the design, implementation, and management of PSS in the built environment.

The findings from this analysis will be used to develop a model illustrating the relationships between factors and each property/characteristic. This model will serve as a visual tool to help stakeholders understand and navigate the complex interplay between these elements, and to identify opportunities for optimization and improvement within the PSS framework. In the conceptual model in figure 3.4 the relationship will be indicated with an arrow in both ways, however in chapter 5 for each property/characteristic a model is made where the relationship between with each factor is shown.

3.2.2 Conceptual model

The conceptual model in figure 3.4 incorporates all the concepts identified as impacting a PSS in the built environment. This model forms the conclusion of the literature review. A successful PSS can contribute to a circular economy. The product in this PSS is influenced by multiple aspects. The aspects that influence the product are divided into the properties & characteristics of a product and the factors that surround the product. Firstly, stakeholder-influenced factors such as collaboration, product design, resources used, contract models, and ownership are crucial. The chosen contract models and ownership structures within a PSS are shaped by Dutch property law, signifying its importance in PSS implementation.

Secondly, the literature underscores the crucial role of product properties and characteristics, including durability, repairability, (re-)usability, customizability/standardization, modularity, environmental sustainability, and economic viability. These all play an integral role in determining the success of a PSS. This comprehensive model provides a robust foundation for exploring and addressing the research questions.

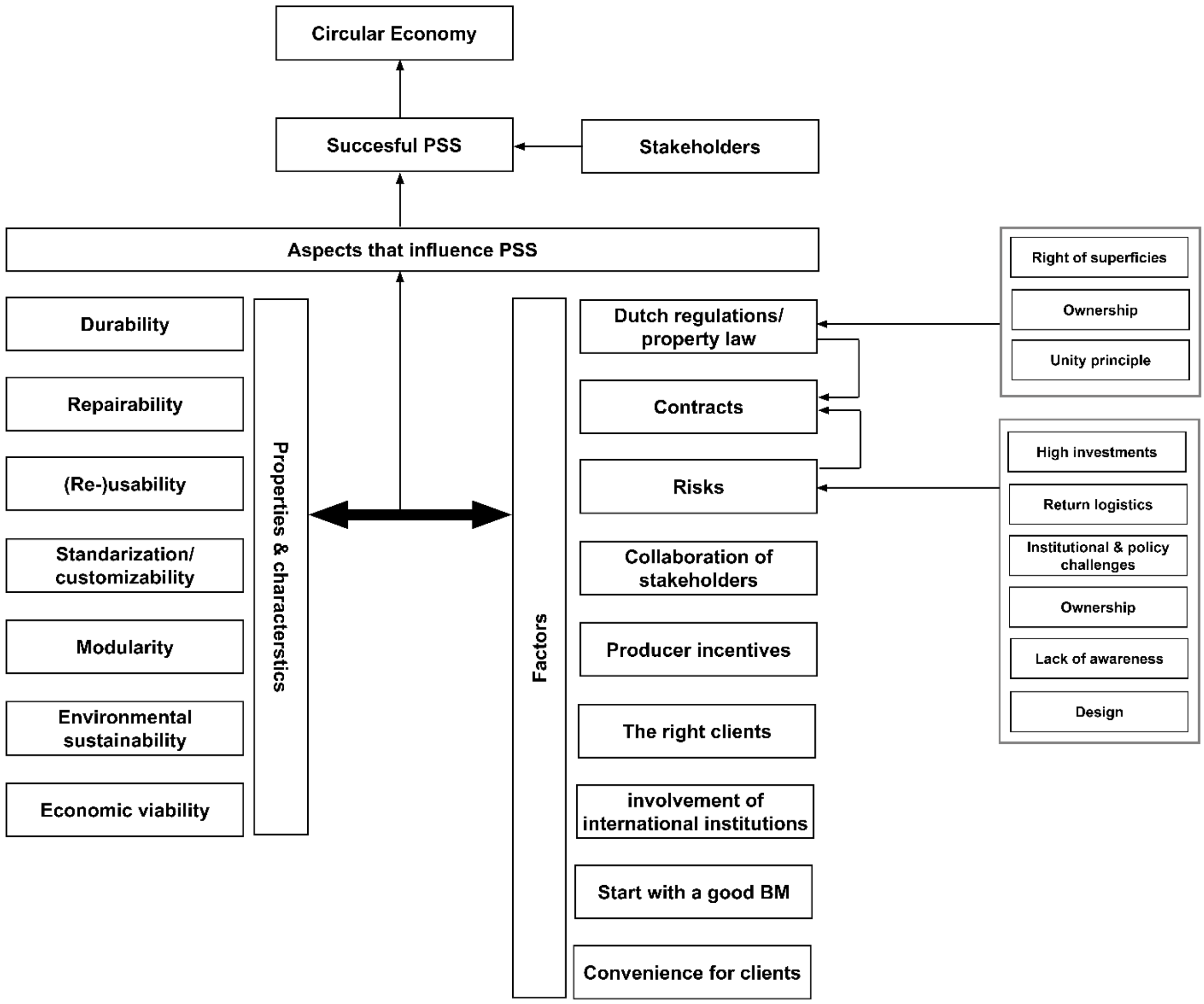

Figure 3.4: conceptual model (own figure)

3.3 Investigation of existing PSS

To gain better insights into the working of PSS, existing systems will be evaluated. This will provide real-world illustrations of how PSS can be successfully implemented, offering valuable insights that may inform future endeavours in this domain. The investigated PSS serve as pragmatic blueprints for understanding the diverse facets and nuances of PSS, ranging from their formation to their operation. By studying existing PSS, a better understanding can be comprehend of the critical factors and conditions that facilitate the successful deployment of PSS.

A minimum of three cases will be thoroughly investigated on their economic, financial, legal/contracts and technical/design aspects. An important disclaimer is that when the literature does not seem to have enough information of the cases to be useful for this research than extra information will be gained to treat the case as a 'new' case study. Based on the research questions and goal, the following criteria selection are used to select cases:

- Relevance: Cases should be relevant to the research questions and goal, which is to investigate the application of PSS in the Built Environment as a solution to create a more circular economy.

- Diversity: Cases should represent different PSS models and sectors preferably within the Built Environment. This enables a broader understanding of PSS and their applicability across different contexts.
- Complexity: The case should be complex enough to provide insights into the challenges of implementing PSS in the Built Environment, such as stakeholder engagement, product design, and service delivery.
- Availability of data: Sufficient data should be available to conduct an in-depth analysis of the case. The cases will be done through a literature research, therefor it is important enough data is available and the quality of the data is sufficient. The data should include both qualitative and quantitative information, such as interviews, surveys, and financial data.
- Innovation: The case should be innovative in terms of its PSS design, business model, or service delivery approach. Innovative cases provide a better understanding of the potential benefits and challenges of PSS in the Built Environment.
- Phase: the product of the case study should be in the operational phase and the plan and PSS are thought out, so the consequences of the model are clear.
- Location: since the Dutch regulations and law, since Dutch law will be applied throughout the research or the case should be similar are as in the study the regulations of the Dutch law can be applied.

3.3.1 Possible PSS in practise

In the following section, we delve into the exploration of potential cases that explain the application of PSS. The subsequent table presents an overview of the identified PSS cases, each underscoring unique aspects of this innovative approach within the built environment.

What	Company	PSS
Façade as a service	TU Delft	Leasing of the façade in the Netherlands
Elevator as a service	Mitsubishi	Leasing of the elevator, only the user.
Solar panels	Sunrun	Purchase of the solar power
Carpets	Desso/ Tarkett	Clients have the option of leasing carpet for a period of 7 years, after which the carpet will be replaced with a new carpet.
Kitchens	Chainable	Kitchen as a service, with all maintenance included, if wanted. They offer multiple contract possibilities for 15 – 20 years.
Infrastructure as a service	Dura Vermeer	Infra as a service involves the use of objects such as a road section, bridge, verge or road lighting.
Movies/ series	Netflix	Product performance: Netflix is one of the best examples of subscription-based business models. The company has managed to build a viable consumer subscription-based business on a large scale with a simple subscription service.
Bikes	Swapfiets	Mobility as a service: leasing a bike, with all maintenance included for monthly payments.
Washing machines	Splash	The supplier offers the use of washer and dryers and the users pays regular payments. The suppliers is responsible for the maintenance.
Lights	Philips & Signify	The supplier offers the lighting instead of the light bulbs. The suppliers is responsible for the maintenance.
Music	Spotify	Product performance: Also a subscription-based business model.
Pay per copy	Xerox, Canon and OCE	
Books	Amazon Kindle	Selling content instead of the product

Cars		Cars as a service refers to the car leasing many business have in place for their employees.
Fitness	Peloton	Fitness as a service, at home fitness service
Healthcare	Philips	Healthcare providers have access to a wide range of subscription-based services through a PSS model
Transport	Mike Albert Fleet Solutions	The term "transportation as a service" refers to the purchasing of miles, trips, and/or experiences without having to deal with any of the hassles associated with vehicle ownership, such as finding and paying for storage space as well as buying and financing vehicles, maintenance, petrol, insurance, traffic, and actual driving.
High pressure cleaners	Boels	The company sells a spotless driveway or patio and not the pressure washer itself
Aircraft engines	Rolls-Royce	TotalCare service of Rolls-Royce removes the burden of engine maintenance from airlines and assumes the associated risks. Rolls Royce makes money when its engines are in use and the airline makes money when its aircraft are in use.
Strollers	Bugaboo	Renting a stroller, which can be changed according to the needs of the family.

Figure 3.5: Possible case studies (Own figure)

3.3.2 Case study selection

The cases were selected on the following criteria: relevance, diversity, complexity, availability, innovation, phase, and location (relevant for the Netherlands). After applying the selection criteria the selected cases were: Façade as a service from TU Delft, Mobility as a service from Swapfiets and elevator as a service from Mitsubishi.

- **Relevance:** Each of the chosen case studies represents a critical aspect of the built environment or related services, which are directly relevant to the topic of PSS in the BE. Facades (Aguerre et al., 2019), elevators (Mitsubishi Electric, n.d.), and bike-sharing systems (Swapfiets, n.d.) all have significant implications for sustainability and resource efficiency, aligning with the goals of PSS.
- **Diversity:** The cases cover a diverse range of PSS applications, from building components (facades) to transportation systems within buildings (elevators) and products not related to the BE that deals with a lot of customers (bikes). This variety enables a comprehensive understanding of PSS across different sectors and applications within the built environment, which is essential for generalizable insights (Yin, 2017).
- **Complexity:** Each case presents unique challenges and complexities associated with PSS implementation, such as design, maintenance, and end-of-life considerations. By examining these complexities, the research can provide in-depth insights into the factors that influence the success or failure of PSS initiatives (Johnson et al., 1996).
- **Availability:** The selected cases are well-documented, allowing for a rich and detailed analysis of their respective PSS models. Access to information and data is a critical factor in case study research, as it facilitates robust and reliable findings (Yin, 2017).
- **Innovation:** The case studies showcase innovative PSS models in their respective domains, highlighting the potential for novel approaches and solutions to drive sustainability in the BE (Tukker, 2015).
- **Phase:** Each case study is at a different stage of the operational phase of PSS implementation and maturity, providing insights into various stages of PSS development and the associated challenges and opportunities (Baines et al., 2007).

- **Location:** All three cases have a strong connection to the Netherlands, ensuring that the findings are relevant and applicable to the local context. This is particularly important for research focusing on the BE, as policies, regulations, and market conditions can vary significantly across countries (Tukker, 2015).

3.3.3 Reviewing the cases

Each PSS will be reviewed on their economic, financial, legal/contracts and technical/design aspects. This is an effective approach to understanding the complexities and challenges associated with the implementation of PSS in the BE. This approach is supported by several scholars who emphasize the importance of evaluating multiple dimensions of PSS (Baines et al., 2007; Tukker, 2015). Focusing on these aspects in each model allows to capture the diverse factors influencing the success or failure of PSS in the built environment. The economic and financial dimensions of the cases provide insights into the feasibility and profitability of PSS models, while the technological and design aspects explore the practical implications of designing and implementing PSS solutions. Furthermore, the legal and contractual dimensions highlight the role of policies, regulations, and contractual agreements in shaping the implementation and success of PSS. By investigating multiple systems, the PSS can be compared and contrast the experiences and challenges faced by different organizations or projects, identifying patterns and trends that can inform future PSS implementation. Moreover, this approach allows to generate rich and detailed insights into the contextual factors and processes shaping PSS outcomes, contributing to a more comprehensive understanding of the topic (Stake, 1996).

3.4 Empirical research

The methodology for the empirical part of the study is described in more detail in this paragraph.

3.4.1 In depth interviews

The method of gathering data for this study are in-depth interviews where semi structured method is used. An interview protocol is established prior to the interviews This semi-structured interview technique provides as a guide, but it also allows the freedom to make sure that the participant's entire experience with the subject is shared. The technique enables respondents to discuss what they believe to be essential (Morris, 2015). Only a few pre-determined questions will be asked during the semi-structured interviews; the other questions are made on the spot and will follow the flow of the conversation. Additionally, semi-structured interviews may be used to compare interviewees in a way that is more objective. Therefore, semi-structured interviews provide the benefits of both structured and unstructured interviewing methods. The interviews will be held online through teams, this will give the interviewees more flexibility of when the interview will take place and schedule wise easier to plan the interviews in a shorten period of time. Also doing the interviews will provide an automatic transcription and video of the interview that will record everything said in the conversation. This will make sure all the information is noted.

There is some variety in what is suggested as a minimum amount of interviews for a qualitative research. Many different researchers claim that between 5 and 50 interviewees are enough (Dworkin, 2012). For this research the goal is to get the perspective of different professionals in the field who have different roles in the PSS process. It is important for the interviews that there are interviewees from different disciplines included, so that the PSS is viewed from multiple angles. The goal is to have participants with both a negative and a positive view for using PSS in the BE to get a more complete picture in the why. With the scope and timeline of this research in mind the amount of interviews is set to ten interviews. If findings of an interview are limited or an interviewee does not have enough knowledge about the subject the amount of interviewees will raised.

3.4.2 Selection of interviewees

The interviewees will be chosen through purposive sampling (Blaikie & Priest, 2019). The network of the interviewee will be employed in the snowball sampling so that individuals may find additional professionals who have the right traits. There will be a variety of subjects explored throughout the interview. The experience of the interviewee is a crucial since more experience will lead to more useful answers for this research. A list of characteristics is established that a participant must meet:

- Experienced professional in the BE with knowledge of the CE and the workings of products as a service.
- Experienced in the Dutch market and acquainted with the Dutch regulations.
- Different roles within the circular supply chain should be represented among the participants.
- Different disciplines should be distributed among the participants.

3.5 Data collection methods

The last part of the research is interpreting and reporting. All the sub questions have been answered and will be analysed and the main research question will be answered. The answer will be an overview of properties that different building components should have and their possibilities for a product service system. The legal and financial implications are taken into consideration. Lastly, the research will be questioned in the discussion and further research implications will be given.

Blaikie and Priest (2019) mention three types of data that can be collected: primary, secondary and tertiary. In this thesis primary and secondary data will be used. The primary data is information generated by the researcher and will come mostly from the in-depth interviews. The case studies will be a combination from primary and secondary information. Information of cases found by other researchers and information gained through access into the cases will be used. The primary data will consist of previous published articles and publications of other researchers.

3.6 Data analysis

As described in the previous section multiple data collection methods will be used. First a literature study will be conducted to find the concepts and background behind the research. This will create a framework for the rest of this research. Next different successful PPS cases in literature will be investigated. This together with the literature review will give an overview of all necessary properties a product needs to have to be used as service. This will form the basis for the in-depth interviews, where experts will be interviewed the possibilities and if they see what products are fit to become a PSS. These interviews will be held online in teams. Afterwards each interview will be transcribed and coded with ATLAS.ti. ATLAS.ti is a qualitative research tool that could be used for data visualisations, literature reviews, network diagramming and coding of transcripts and notes. In this research ATLAS.ti will be used to code/tag and annotate features within the bodies of unstructured data provided by the interviews. The coding will help visualizing and recognizing relationships the networks between different concepts in the interviews.

3.7 Data plan

This data management plan will emphasize and reflect on why certain approaches for the data plan are chosen. The data will be collected through in depth interviews. Only relevant personal information will be requested during interviews; if the interviewee provides more information than is required, that information won't be recorded or removed. The project storage drive will house all of the data. The data can only be controlled by the drive's owner, and it may be shared by providing the appropriate connection to the authorised individual. They are not permitted to modify the data or disseminate the information. Through the literature review and interviews, all the information will be gathered. The interviewees will need to complete and sign a permission form. If a respondent or interviewee has not completed this form, their information will not be utilised for the study. This consent form will specify that the data will be used and processed. This will be carried out to avoid any legal repercussions.

This research will handle the privacy of tis participants carefully. The findings won't be affected by the personal information (such as age, gender, or names), thus it won't be disclosed to anyone else. Email addresses and other personal information will not have been disclosed to anyone else and will only be used by the researcher.

The data will be shared and made public under the TU Delft Research Data Framework Policy without any identifying information. Throughout the project, the project manager will be in charge of access permissions. The data will be made available to the public as soon as the associated research is finished. The occupation of the respondents will be the only personal information that is gathered and shared in the research; this information will be provided because it is anticipated that it lends credibility to the study. The information will be accessible to the general public and usable for further investigation.

The research will be made accessible in the Delft repository of the TU Delft: https://repository.tudelft.nl/. The English language is utilised in this thesis to promote interoperability, and the meanings of the terms employed are well clarified. For the research to be reused, the methodology is fully described. The literature chapter is included at the conclusion of the thesis and contains all of the references, all of which are referenced in APA 7 style.

3.8 Ethical considerations

This study will protect volunteers from damage and any unpleasant emotions they might experience. The participants will be properly informed about all pertinent information, and it will be ensured that they are aware of the project's purpose. The respondents will be completely anonymous, and they will be made aware of how the study will be shared.

The obligations and rights based on universal rules or principles are the tasks of the research (Blaikie & Priest, 2019). By ensuring that the data is gathered anonymously and that direct quotes from participants cannot be linked to specific persons, the researcher will uphold honesty and trust among the participants. Every participant is free to decide whether or not they wish to participate in the study. Additionally, all volunteers are allowed to leave the research at any time, and this will be made clear to them at the beginning of the study. All participants will be aware of the research's purpose and researchers. Written permission to participate will be obtained from each participant. To ensure that all participants understand the nature of the research, this permission form will provide a brief explanation of the goal, methodology, and any alternative techniques that may be employed. All participation-related hazards and discomforts are disclosed, and anonymity is guaranteed. If this consent form is not signed, the respondent's data will not be utilised.

The interviewees won't be harmed by the study. By eliminating the chance that they may be recognised, the participants will be safeguarded. No names or other details that can be used to trace a person will be used in the study. This research will not lead to any significant outcomes that might affect the life of a participant in anyway. The focus of the research lies on the participants knowledge and experience in the work field and how they see future possibilities. The outcome of this research is not related a person or to the personal/ work life of the participant and therefor will have no influence and effect on their life.

CHAPTER 4

FACTORS THAT INFLUENCE PSS

Chapter 4: Factors that influence PSS

PSS operate within an intricate network of influences, both internal and external to the organization. Understanding these factors is crucial for the effective implementation and management of PSS. This chapter seeks to delve into these key factors that impact the establishment and operation of PSS in various industries. Different factors are presented in the literature that have a significant impact on the implementation of PSS. Ploeger et al. (2019) states that the regulations and laws in the Netherlands profoundly affect the products suitable for PSS. These regulations also influence the types of contracts applicable to PSS. Researchers such as Ploeger et al. (2019), Mohammadi & Slob (2016), and Castelein (2018) have explored diverse contract possibilities for the circular economy and PSS implementation. Furthermore, incentives for producers play a crucial role in adopting PSS. The producer's influence on the product requires either intrinsic motivation or financial stimulation to incorporate PSS in their business. Additionally, it is essential to consider the risks faced by the different stakeholders, including high investments, return logistics, design, institutional and policy challenges, and ownership issues. By exploring these aspects, the chapter provides a comprehensive understanding of the context within which PSS function, offering insights that can inform the development of effective strategies for PSS implementation and management.

4.1 Legal concepts and their implications for PSS

In order to comprehensively examine PSS and their potential implementation within the built environment, it is crucial to explore the legal concepts that govern and shape the PSS landscape. This chapter delves into the legal aspects of PSS, focusing on specific concepts that play a vital role in determining the feasibility and success of PSS in practice. The discussion encompasses the following legal concepts: ownership (im)movable property, principle of unity, accession and right of superficies.

By examining these legal concepts and their implications for PSS, this chapter aims to provide a comprehensive understanding of the legal landscape surrounding PSS, as well as to identify potential difficulties for addressing the legal challenges that may arise in PSS implementation and operation.

4.1.1 Property law

Property law has a closed character, meaning that only those property rights recognized by law can be utilized. Two individuals cannot establish new property rights that are not provided for in the law. These rights, such as ownership, ground lease, and mortgage, are transferable and therefore considered property rights (Huls, 1999). Property law, particularly concerning proprietary rights and interests, governs the relationships between natural or legal entities and legal objects, such as goods. This area of law specifically addresses various forms of land or (immovable) property ownership and provides the legal foundation for property transactions and property rights (Koolhoven, 2018). By defining what constitutes a good, who is granted a property right, a security right, or a right of use over it, the powers associated with it, and the transfer process of that right to another party, property law ensures clarity and certainty for all parties involved in business transactions.

Implementing PSS in the built environment can pose challenges under certain circumstances, particularly when the ownership of the product changes (Ploeger et al., 2019; Koolhoven, 2018; Van de Vondervoort, 2019). Property law, especially in the context of the construction sector, can hinder circularity due to the current provisions in the Dutch Civil Code's Books 3 and 5 (Pierik, 2018). This chapter will delve into the most critical legal aspects relevant to PSS within the construction sector, exploring how they may impact the circular economy and under which conditions.

4.1.2 Ownership

In Book 5, Article 1 of the Dutch Civil Code ownership is defined as “The most comprehensive property right that a person, the ‘owner,’ can have a thing”. Under Dutch property law, the owner of property has the freedom to use, dispose of, and encumber the property as they see fit. This idea is known as "absolute ownership" (Akkermans, & Van Erp, 2010).

4.1.3 Immovable property (= in Dutch onroerende zaak)

According to art. 3:3 of the civil code immovable properties are the land, unexploited minerals, vegetation united with the land, as well as the buildings and structures permanently united with the land, either directly or by association with other buildings or structures" (art. 3:3 lid 1 BW).

Art 5:20 of the Dutch civil code states that the owner of the land is also owner of all buildings and structures are sustainable united with the land and is counted as immovable property (Ploeger et al., 2019). To the extent that the law does not provide otherwise, ownership of land includes (art. 5:20 lid 1 BW):

- The topsoil;
- The earth layers located underneath;
- the groundwater brought to the surface by spring, well or pump, water that is on the ground and is not in open communion with water in someone else's yard;
- Water that is on the ground and is not in open communion with water in someone else's yard;
- Buildings and structures permanently connected to the ground, either directly or by association with other buildings and structures, to the extent that they are not part of someone else's immovable property;
- Plantations united with the land.

4.1.4 Principle of unity

The determination of ownership guarantees clarity and certainty for all parties in trade and offers advice in transactions (Koolhoven, 2018). Article 5:3 of the Dutch Civil code determines the extend of the right of ownership: the owner of a good is also the owner all the components of that good. This stems from a fundamental principle: the unity principle (van der Plank, 2016). This means that numerous components are considered as a single entity for the purposes of property law (Koolhoven, 2018). Van der Plank (2016) states that it would be undesirable for anything that appears to be a whole could actually consist of several, fractured property rights.

The unity principle in property law is closely related to the principles of trust and publicity, as it suggests that an object is considered a single unit with one quality if perceived as such by common opinion (Koolhoven, 2018). The effectiveness of property rights, which are absolute and apply to everyone, relies on their observability or knowability, which in turn depends on this assumption (Koolhoven, 2018). In the context of the built environment, this principle implies that a building is viewed as a whole entity, encompassing its roof, walls, doors, windows, etc., and when purchased, the entire building is owned and used by the buyer (Koolhoven, 2018).

4.1.5 Accession (= in Dutch natrekking)

Accession is a type of property acquisition and loss that doesn't happen through ownership transfer. An object loses ownership of that section when it merges with the main object (Van der Plank, 2016). From the standpoint of property law, the object that has been incorporated into the primary entity loses its autonomy and disappears (Van der Plank, 2016). As stated in Article 5:3 BW, the owner of the principal object now benefits from an extension of his ownership. There are general and specific conditions in the law regarding the subject of whether one object is subject to accession by another object (van der Plank, 2016).

In Article 5:3 BW, which states that components are subject to accession by their main components (Van de Vondervoort, 2019). As explained in the ruling ECLI:NL:HR:2018:2256, the general principle of accession applies to all types of objects, whether movable or immovable (Van de Vondervoort, 2019). Under Dutch law, an object is considered a component of a main object if it is perceived as such by public opinion. Furthermore, an object becomes part of the main object if it is so integrated with it that separating them would cause significant harm to one or both objects (Ploeger et al., 2019). The rule of accession, applicable to both movable and immovable property, can be found in Article 3:4 BW (Van de Vondervoort, 2019).

The general method of accession is based on constituent elements of objects under Art. 3:4 BW. It is not relevant whether an object qualifies as immovable and is therefore can be acquired by accession. Art. 3:4 BW has two paragraphs:

> 1. Anything which, according to the common opinion, forms part of a thing is a component of that thing.
>
> 2. An object which becomes connected with a principal object in such a way that it cannot be separated from it without significant damage being caused to one of the objects becomes an element of the principal object.

According to the supreme court when a building and equipment located therein are structurally matched, therein lies an indication that building and equipment are to be regarded as one entity according to the common opinion (2013, ECLI:NL:HR:2013:CA0813)

The same applies when, from the point of view of suitability for example a factory building, the building is to be regarded as unfinished in the absence of the equipment (van der plank, 2016). This is called the in-completeness test, which means that in absence of particular components a building cannot be considered complete and fit its purpose.

The common opinion plays an important role with regard to the manner of accession. Van de Vondervoort (2019) mentioned that the common opinion plays a role in the interpretation of the concepts 'durable', 'united' and 'made known to the outside world'. In the general mode of accession, the yardstick of common sense is used when answering the question of whether the whole can still fulfil its social purpose if a particular component were missing (Koolhoven, 2018). Remarkably, current common opinion views towards building components are generally geared towards unification of building components with the whole (Koolhoven, 2018). The origin of this view, as Ploeger et al. (2016) argued, lies in the presence of the unitary principle in the current, linear construction economy. In the construction industry trading relationships are still very linear focused, where an ownership transfer of the product takes place (Van de Vondervoort, 2019).

4.1.6 Right of superficies (= in Dutch opstalrecht)

Article 5:101 BW dictates the right of superficies:

> 1. The right of superficies is a right in rem to own or acquire buildings, structures or plantations in, on or over an immovable property of another.
>
> 2. The right of superficies may be granted independently or subject to another right in rem or a right of lease or rent on the immovable property.

3. The deed of establishment may impose an obligation on the claimant to pay the owner a sum of money - the fee - at regular or irregular intervals.

This means that the right of superficies comprises the right of the superficies holder to have buildings, structures or plantations in, on or above the immovable property of another. These buildings, structures or plantations are the property of the claimant. The owner of the immovable property must tolerate it. A good example of the right of superficies is often used with the laying of water pipes or electricity. If these pipes or cables run through someone else's land, they do not become the property of the landowner.

4.2 Consequences of different legal concepts on PSS

Dutch property law can cause various challenges for the implementation of PSS. The important and most influential existing legal concepts found in literature are: ownership, unity principle, ownership of immovable property, accession and common opinion. These concepts can pose as a barrier for successful implantation of PSS and the wider adoption of the circular economy.

The concept of ownership can pose challenges to the adoption of PSS, as it can obstruct the sharing of resources and hinder the transition towards a circular economy (Stahel, 2016). Owners may be reluctant to relinquish control over their property or assume additional liabilities, creating obstacles for the adoption of PSS. Furthermore, current property laws may lack the flexibility required to accommodate innovative approaches that promote resource efficiency and value creation (Ghisellini et al., 2016).

Although these legal challenges are not new, and exceptions already exist, involved parties must explore alternative methods to navigate property laws when incorporating PSS (Van Vliet, 2002; Mostert et al., 2010; Van der Walt & Sono, 2016; Mes et al., 2016). Legal security and preservation of value are key motives in seeking exceptions to property law. Adopting circular economy principles, such as implementing object such as: stairs, windows and doors as separate components with supplier ownership, can lead to value creation and standardization, rather than loss of value associated with traditional building ownership (Ploeger et al., 2019). Ultimately, understanding and addressing these legal challenges are crucial to fostering the successful implementation of PSS and promoting the transition towards a circular economy.

The unity principle does not align well with the Circular Economy and the use of PSS, as the emphasis is on usage rights rather than property rights (Van de Vondervoort, 2019). This principle may restrict the potential for modular design and the reuse of individual components, which are essential aspects of a circular economy (Bocken et al., 2016).

The concept of common opinion can be disadvantageous for PSS and manufacturers in terms of ownership. However, a shift in this traditional trading approach may occur as circular trading relationships become the new standard. Leasing interior walls, facades, and kitchens is not yet a standardized practice in the construction industry, but as more circular programs emerge, a breakthrough may be imminent (Van de Vondervoort, 2019), potentially changing the common opinion. The common opinion will be a decisive factor in determining whether or not objects can be gained through accession by other objects. Additionally, a change in common opinion may require the adaptation of legal frameworks to better support circular business models and PSS (Murray et al., 2017).

4.3 Possible solutions for PSS

When inadvertent transfer of ownership by accession takes place, but there is a lease contract for the product than parties are still obliged to comply with the lease agreement. If a company fails to honour the agreement after the term of commitment ends than according to article 700 of the Code of Civil Procedure, the supplier of the product can levy an attachment on the product to secure the product for as long as possible (Van de Vondervoort, 2019).

The supplier of the product could also ensure that they get the money invested in the product back, without starting legal proceedings. In this case they should stipulate a penalty amount in the lease agreement (Art. 6:91 BW) to ensure that they will receive a sum of money in case there is a breach of the obligation, which exceeds the value of the product (Van de Vondervoort, 2019). However it is important to note that this goes against the principles of the circular economy, when not reusing the product, but gaining a larger sum of money.

In fact, therefore, a contractual obligation may provide sufficient safeguards to ensure that the product will be returned to the hands of their producers, despite the accession regulations in the law. According to Van de Vondervoort (2019) the lease agreement seems to be a suitable instrument for the circular construction sector. However, that may be different if there is a bankruptcy. When leasing is a possibility from a legal point of view than still more precise contractual terms must be drafted in order to account for the bankruptcy of either the client or the provider. Given the risk associated with the collateral, operational leasing appears to only be feasible for clients that have a very high level of undeniable reputation or in other instances where the risk associated with the revenue streams for the funders is decreased (Hieminga, 2015). When bankruptcy does occur it is important that the manufacturers could stipulate, when installing their product in the building, the registry property, of the purchasing company, that the owner of the building must tolerate access to the building for repossession of the façade panels once the façade panels have been in the building for 10 years or the owner of the building stops paying the periodic lease fees (Van de Vondervoort, 2019).

4.3.1 Right of superficies as a solution

To establish the right of superficies or building lease on a product might be an option to avoid an unintended transfer of ownership by accession and therefore no longer depend on a contractual obligation in case of bankruptcy. This is a restricted property right, which allows the lessee to possess any structures, on, or above land that is not their own (Akkermans et al., 2008; Bartels & Van Velten, 2017). The structure should be an sufficient independent and can be separated from the land and building. The extent of individualization for specific property depends on the prevailing views of general opinion (Hoofs, 2013). Moreover, a prerequisite is that the individualized constituents are registered and can be located in a designated register (Koolhoven, 2018). In conclusion, the right of superficies cannot be established for property that is not adequately individualized and cannot be economically exploited as a separate entity.

4.3.2 Madaster

With contemporaneous technology it is possible to individualise and record everything in a deed, an example of this is Madaster. Madaster gives building components a materials passport that can be viewed on its website. If the information of these building components is published through a platform like the Madaster, or for facades in particular the Facade Identification System, then citizens have the opportunity to know not only the materials passport but also who the developer and owner of the product is (Van de Vondervoort, 2019). However establishing superficies on every single building component would be laborious and impractical in day-to-day installation practice and therefore inefficient (Koolhoven, 2018). Establishing rights of superficies can be a bureaucratic disaster and is also very costly, therefore a simple lease agreement, whether or not another variant of a commitment that aims to take back/return (e.g. purchase agreement with buy-back guarantee) , offers a cheaper and practical solution (Van de Vondervoort, 2019).

4.3.3 Adjustments of the law

Ploeger et al. (2019) states that from a legal point of view there still are a lot of uncertainties that need to be solved and the Dutch property law is still not in line with the circular economy. Adjustments to the Dutch law and then especially the civil code would make it easier to adapt a circular economy.

4.4 Liabilities & legal uncertainties in retaining ownership

An important part of using PSS in the built environment are the responsibilities of the product, as stated earlier, when the user of the product is not the owner this can lead to carelessness of the user (Tukker, 2004). Using PSS often involves multiple parties, such as the owner, the user, and the service provider. Dutch tenancy law can create challenges when it comes to allocating responsibilities and liabilities between these parties (Ploeger et al., 2019). For example, it may not be clear who is responsible for maintenance or repair of the product, and who is liable for any damages to the product. Therefore, it is essential to establish clear contractual frameworks and well-defined legal structures that address these issues, ensuring a smooth and effective implementation of PSS in the built environment. PSS can be divided into three different types: product, use & result oriented. These each have different characteristics and shift in ownership and need a different type of contract.

Product oriented services

Product-oriented services only provide a little amount of service in exchange for a significantly bigger product share. "Product-related services" and "advice and consultation" fall under this category. In both situations, a product is exchanged during the transaction, and services are occasionally offered following the transaction. Examples fall under "Product-related services" under "Take-back guarantees," "Advice and consultation" under "Advice and consultancy," and "Product-related services" under "Product-related services" (Djoegan, & Reek, 2016; Tukker, 2004).

Use oriented services

Services that are usage-focused go a step farther. In this category, the provider retains ownership of the product, and the consumer simply purchases the service rather than the actual goods. For instance, this might happen through leasing, product renting, or product pooling. The exclusivity of utilising a product determines how the many possibilities differ from one another. When a user leases a product, that person has exclusive access to it. With product rental many users rent a product, they can all use it simultaneously. When multiple users pool products, a product is used sequentially by all of the users. Examples include renting a caravan, using a flex space, and leasing cars (Tukker, 2004).

Results-oriented services

Result oriented services consists of a collection of transactions where the emphasis is on the result of a service rather than a product. An example is a laundromat, where customers only want their laundry to be clean; they don't require a washing machine. Only a single payment is needed to achieve this: Pay-per-us. The terms "outsourcing (activity management)" and "functional result (functional result)" are also used to describe transactions in this category. A request is given to a contractual party in outsourcing, and then a certain outcome is anticipated. The most severe type of result-oriented service is functional result. Here, a supplier and customer make a deal for the delivery of a result. Here, a supplier and customer make a deal for the delivery of a result. The manner in which a specific demand is satisfied throughout the length of the contract is then left up to a market party (Djoegan, & Reek; 2016; Tukker, 2004).

4.5 Contracts

Contracts are agreements between two or more parties. In the Netherlands art. 6.213 CC provides the following definition:

> *"A contract within the meaning of this title is a multilateral legal act, whereby one or more parties enter into an obligation towards one or more others."*

A contract is between at least two parties and its terms are governed by contract law. With PSS, the focus lies on selling the service instead of the product, requiring different models and contracts than with the linear model. A key component in the successful implementation of circular business models is the establishment of well-structured contracts that address the unique characteristics of CE. Ploeger et al. (2019) highlight that the widely advocated option of retaining ownership of building parts within the CE context leaves legal uncertainties, which can hinder the development of circular business models. This is especially true for immovable property and fixtures. The authors suggest that alternative approaches, such as buy-back and take-back contracts, as well as models for reuse and recycling, may offer more promising solutions for businesses operating within the CE framework. Using PSS in the built environment comes with different challenges, and traditional contracts are not always suitable for these systems. In the following paragraphs the most common contract forms for PSS' are discussed: financial lease, operational lease, and pay-per-use, and buying with take-back/ buy-back guarantees.

4.5.1 Financial lease

A contract type is financial leasing, the user leases the component with the assumption that ownership would be transferred at the end of the lease period (Tardi, 2022). An advantage of financial lease is that this contract model allows the customer to access and utilize the product, without paying the entire costs of the product upfront. The user makes periodic payments throughout the lease term, which can help manage cash flow and reduce the financial burden associated with purchasing the product (Tardi, 2022). This strategy gives the consumer the opportunity to eventually own the product or service while still enjoying its benefits throughout the lease period. Financial leasing arrangements make it easier to adopt PSS since it gives both parties flexibility and ensures a smooth transfer of ownership. By encouraging resource efficiency and prolonging the lifespan of products.

4.5.2 Pay per use

In the pay-per-use contract model for PSS, users are charged based on their utilization of the product. For instance, Philips' "pay-per-lux" model involves customers paying for the actual use of lighting systems (Philips, 2021). Another example is a coffee machine where users pay per cup dispensed. In such cases, the manufacturer, who also retains ownership of the product, assumes the majority of financial risks (Baines et al., 2017). The ownership typically lies with the supplier or leasing company, emphasizing the service aspect of the arrangement rather than the product itself (Tukker, 2004). This can be a good option for products that are used infrequently or for a short period (Ceschin & Gaziulusoy, 2016).

4.5.3 Operational (full service) lease

An operational lease for PSSs is a specific kind of leasing contract where a party (a corporation, business, or customer) leases a product and is responsible for all related operational expenditures, sometimes including maintenance and repair. The capital costs, such as the price of buying or financing the equipment, are the responsibility of the lessor, or the business that owns the equipment (Tardi, 2022). This kind of lease is frequently used for expensive, highly specialised, or frequently in need of repair or upgrade equipment. Companies are able to acquire the equipment they want without having to make a sizable capital expenditure, and it helps them plan their operating expenses more effectively. Ploeger et al. (2019) mentions different companies that have already implemented this kind of processes. Using lease contracts can also assist businesses in staying ahead of technological advancements and lowering the likelihood of equipment breakdowns (Philips, 2021). More recently operational lease is also used within the circular economy. Given the risk associated with the collateral, operational leasing appears to only be feasible for customers that have a very high level of undeniable reputation or in other instances where the risk associated with the income streams for the funders is decreased (Hieminga, 2015).

At the moment, performance-based contracts, like leasing, constitute the foundation of the most well-known circular procurement models. It's crucial to understand that this is not (yet) done for long-cycle products, therefore leasing is not utilised as a contract for the realisation of a whole structure but rather for the delivery of a component in the form of a service. Functional procurement and product-related services, including buy-back agreements, are primarily utilised when constructing a whole building (Mohammadi, & Slob, 2016).

Ownership of a product is transferred from the client to the provider during the term of a lease arrangement. This makes it necessary for businesses to create durable, high-quality products or face hefty maintenance expenses, which also increases the possibility that a product will be reused. A provider's focus is shifted from short-term to long-term as a result. The business model makes sense if material costs rise because suppliers can use their rising capital (EMF, 2013a). Nevertheless, leasing of all building elements is not yet a possibility, claim Mohammadi & Slob (2016). Service providers must deal with a sizable quantity of "dead weight" capital since the investment is too large relative to the lifespan of the buildings (Mohammadi, & Slob, 2016). Today's materials not only add dead weight, but they also lose a lot of value over time. Hence, only if material prices rise and a sizeable start-up budget is allocated would it be feasible for long-term projects (Djoegan, & Reek, 2016).

Castelein (2018) mentioned in her master thesis (research for contracting in a CE) that an integrated (Lease) and traditional contract model are most used in circular building projects. However Ploeger et al. (2019) also states that operational lease does not yet offer a solid basis within the CE and therefor other options are suggested such as take-back/ buy back schemes.

4.5.4 Buyback and take back contracts

The key is to consider circular solutions that actually match the situation at hand. Thus, take-back and buy-back agreements are a viable choice. This is an agreement that may be appended (as an annex) to both conventional and integrated construction contracts that states that the supplier or contractor has an obligation to purchase back larger portions of a building at the end of the contract period to an agreed residual value (Ploeger et al., 2019). Using these contracts results in a real sale, making it a more financially feasible choice for suppliers than leasing. It is anticipated that suppliers returning their own goods will be more inclined to repurpose them in the following cycle. With no further agreements, the provider is not liable for maintenance and does not feel accountable for the goods during the usage phase, therefore the circular influence is smaller than with lease contracts. To boost the motivation for producing high-quality items, this should be included in a separate clause. Nevertheless, because take-back is frequently not currently a part of its business model, a contractor does not have as many incentives for reuse after take-back as with leasing. It is a step in the right direction, though. It is also less complicated legally (Djoegan, & Reek, 2016). Buyback is already being effectively employed in a number of projects, notably for short-cycle items that are not closely related to a structure. So, it might serve as a first step towards leasing models and buy-back contracts for long-cycle construction components (Mohammadi, & Slob, 2016).

Another example is the buyback guarantees on iron beams (Nasir et al., 2017). As a result, various specifications are made for building design; the structure must be demountable and constructed from circularly responsible materials (Djoegan and Reek, 2016).

4.6 Incentives for producers

A substantial portion of the planned PSS would involve items returning to the provider, PSS present a chance to adopt new revenue models that emphasise reuse, which has circular advantages. To accomplish circularity, a financial motive for the producers are necessary. Expenses are rising and companies are often the first to cut back on sustainability; however, this tendency diminishes as the use of sustainable materials becomes more profitable (Djoegan, & Reek, 2016). 'Pay per lux' from Philips is a good example. Because of this model Philips is driven to design light bulbs that burn for a long time since the consumer only pays for the light hours (Philips, 2021). In a linear consumption model the company relies on the repeated sales and long term working products would not be beneficial, but with the benefits lie with giving the bulbs the shortest possible lifespan that is still accepted by the buyer. The 'pay per lux' model ensures that Philips will provide better quality with a longer lifespan. This approach ensures that the mechanic does not need to visit monthly for replacement work.

In case 2 (explained in Appendix I) there was stated that the intrinsic motivation from the CEO of Delta Development played a big part in creating a PSS out of the elevators. He aimed to illustrate that this innovative framework, promoting circularity, has the potential to deliver significant benefits across multiple levels and to a broad spectrum of stakeholders. This was especially important for the Park 20/20 project (explained in Appendix I), since the project had certain circular and sustainable goals.

4.7 Risks for stakeholders

PSS have gained increasing attention as a promising approach to adopt sustainability and circularity within various industries (Tukker & Tischner, 2006; Mont, 2002). However, implementing PSS can present certain risks for stakeholders, including manufacturers, suppliers, and customers (Baines et al., 2007; Tukker, 2015). This paragraph will briefly explore some of the potential risks associated with PSS adoption, such as changes in the BM, increased complexity of operations, and potential legal and financial challenges (Reim et al., 2015). Understanding these risks is essential for stakeholders to make informed decisions and devise effective strategies for successfully adopting PSS in their organisation (Kuijken et al., 2017).

4.7.1 High investments needed

Many researchers have identified barriers for stakeholders when it comes to PSS. One such barrier mentioned is the high investment required for a PSS to work. Kirchherr et al. (2017), Koukopoulou (2020), and Kuipers (2021) all mention high upfront investment costs as one of the most pressing barriers. They stated that there are still many learning curves for CE business models to work and that the first one to invest will probably lose a lot of money, while the second investor will earn a fortune. Creating funding for starting with new CE business models could help address this problem; however, there is still not enough funding available (Bocken et al., 2014), thereby creating a hesitant culture.

4.7.2 Return logistics

A functioning return logistics system, which guarantees that the product is returned to the manufacturer so that it may reuse the components and materials, forms the cornerstone of a circular PSS model. Such return logistics are often difficult to set up. Particularly in business to company marketplaces, not all return logistics are appropriate for PSS revenue models. A specific magnitude and/or a high value of the return flow are necessary for in-house return logistics, ideally higher than the cost of the return logistics. In a business to business market for (for example) machinery, this is more frequent than in a business to customer market for consumer items with a high turnover rate (Poolen et al., 2020).

4.7.3 Design

Closing cycles present design challenges. The design of a product is improved incrementally, through trial and error based on experience and data collected on usage, wear, and required maintenance. This process can be accelerated and enhanced by utilizing sensors to monitor the product and its components or by standardizing materials and product elements (Bocken et al., 2016). By adhering to eco-design principles, a product's circularity and sustainability performance can be improved (Tukker & Tischner, 2006). Closing cycles necessitate that the company employing PSS has some degree of influence, either directly or indirectly, over the manufacturing process (Poolen et al., 2020).

4.7.4 Institutional and policy challenges

PSS is suitable for products with innovation-sensitive components; however, the challenge lies in the fact that production is currently more affordable than reuse. Government intervention could significantly contribute in this context. For example, a company that sells or rents refurbished products is required to pay VAT. As a result, tax is paid twice: once for the brand-new original products and once for the refurbished version. To encourage circularity, reduced or zero VAT should be applied to products utilizing recycled raw materials (EY, 2022). Labour-intensive circular processes such as disassembly and remanufacturing are common. Circular operations are facilitated by lower labour taxes and higher levies on the use of new materials (Poolen et al., 2020).

4.7.5 Risks in ownership

The ownership can be divided into Legal and psychological ownership (Etzioni, 1991). Legal ownership is defined as "the ultimate and exclusive right to use, enjoy, inhabit, hold, rent, sell, use, give away, or even destroy an item of property, subject to certain conditions, bestowed by a legitimate claim or title”. Because it does not immediately transmit title, possession (as in tenancy) does not always imply ownership (Demyttenaere et al., 2016). Psychological ownership is the mental state in which people believe that the object of ownership (which can be either tangible or immaterial) or a portion of it is "theirs." The sensation of possessiveness and a psychological connection to the object serve as the basis for this emotion (Pierce et al., 2001). Consuming still places a lot of emphasis on ownership, and alternative ways of consumption where the consumer is no longer the legal owner can have unintended consequences like the user taking less care of the goods (Demyttenaere et al., 2016).

4.7.6 Lacking of consumer awareness and interests

Consumer awareness and interest play a critical role in the success of PSS. The success of a PSS depends on consumer acceptance, adoption, and diffusion. When consumers are not aware of or interested in a PSS offering, it becomes challenging to achieve market penetration and ensure the viability of the business model (Cook et al., 2006). The PSS models often rely on consumers actively participating in the value creation process. PSS models typically require long-term commitments from both businesses and consumers. If consumers are not aware of or interested in the PSS model, securing and maintaining these long-term relationships can be challenging, potentially leading to increased risk for businesses (Mont, 2002). Consumer awareness and interest contribute to building trust and a positive reputation for businesses implementing PSS models. If consumers are not aware of, or interested, in the PSS offering, companies may struggle to establish the trust and credibility necessary for long-term success (Rexfelt & Ornäs, 2009). The PSS model's financial sustainability depends on a consistent customer base.

4.7.7 Other risks for companies:

- Bankruptcy: As mentioned earlier bankruptcy can be a problem when entering into a long term lease contract. Therefor consequences should be well defined within the lease contracts (Van de Vondervoort, 2019).

- Increased complexity: Implementing a PSS model can make the business more complex, as it requires managing a combination of products and services (Tukker, 2004).
- Dependence on customer behaviour: The success of a PSS model relies on customer acceptance and adoption, which can be difficult to predict and influence (Cook et al., 2006).
- Long-term commitment: A PSS model often necessitates long-term commitments from both the company and its customers, which can create uncertainty and increase risk (Mont, 2002).
- Organizational change: Adopting a PSS model may require significant organizational and cultural changes, which can be challenging to manage (Baines et al., 2007).

4.8 Collaboration of the stakeholders

Collaboration and social relationships between all the different stakeholders in the supply chain are important for creating closed looped systems (Bocken et al., 2016; Emf, 2013a). The communication between different stakeholders is crucial for creating good collaborations. When creating new systems within the BE all actors should be brought together, from supplier to designer. It is important that every actor is included, especially the ones normally not involved with the design process, because this will create trust, certainty and open discussion about the process (Barratt, 2004). Leising et al. (2018) has created a tool for supporting the circular economy in the BE. This tool consist out of five different steps that should be taken for creating good collaboration between the different stakeholders:

- *Phase 1 preparation and vision:* co-creation between clients and suppliers of the supply chains is important.
- *Phase 2 involve market and supply chain:* multidisciplinary teams should work together where new type of collaborations between different disciplines emerge.
- *Phase 3 process design and collaboration:* new type of non-traditional contracts between supply chain partners will be formalized and trust is key between the different stakeholders.
- *Phase 4 business model & implementation*: Business models should include a collective aim together with the financial motives of the involved parties.
- *Phase 5 usage and preparation for next use:* this phase should ensure the reuse of the products and that the value is maintained. Products can be divided into long and short term, which each can hold a different type of contract.

Using these steps will ensure joint decision making of the stakeholders and help built trust, which is very important for a good collaboration within the CE (Leising et al., 2018). The multiple parties involved, each with their own goals and benefits , should work together to share the benefits of the project and ensure that the project is economically viable for all parties involved (Mont, 2002). EMF (2013b) stated that with all great transitions there will be losers and winners, but there is an overall growth and winning share.

In summary, when implementing a PSS in the built environment, it is important for stakeholders to work together in an effective and collaborative manner. Stakeholders are important when PSS is used in the built environment because they have a significant impact on the success or failure of the product.

4.9 Finding the right clients

The importance of identifying the right clients cannot be overstated. This is particularly crucial for PSS models like Façade as a Service and Elevator as a Service, as demonstrated by case studies such as the TU Delft leasing project and Mitsubishi's Elevator as a Service (Appendix I).

Housing associations and associations of owners often operate with limited financial resources, making the high upfront costs of significant capital investments, like façade replacements or elevator installations, prohibitive. In such instances, a PSS model that allows for smaller, regular payments spread out over several years can be more financially manageable and appealing. This approach not only ensures a steady revenue stream for the service provider, but also allows clients to maintain and improve their buildings without compromising their financial stability (Azcarate Aguerre et al., 2019)

Institutional building owners, such as universities, government bodies, and corporations, often prioritize their core operations and may not see their real estate holdings as primary assets. For these entities, the high upfront costs of major capital investments can disrupt their cashflows and detract from their primary strategic objectives. A PSS model that distributes costs over a longer period, instead of requiring a large initial investment, can be more attractive to these types of clients. For instance, the Façade as a Service model implemented in the TU Delft leasing project demonstrated how spreading costs over time can align with the financial planning of institutional building owners (Azcarate Aguerre et al., 2019).

4.10 involvement of financial institutions

As the transition from traditional ownership models to PSS continues, the role of financial institutions becomes increasingly important. By financing initial investments, financial institutions can play a critical role in facilitating and encouraging the adoption of PSS models.

In the case of Mitsubishi's Elevator as a Service (Appendix I), one of the main financial obstacles to the success of this new business model was the reluctance of traditional financiers to support it. Existing financial calculation techniques struggled to accurately estimate the risks associated with the M-Use model and the residual value of the lifts. This led to a need for new financial models that could better account for the risks and potential benefits of a PSS.

Financial institutions can provide the necessary capital to kickstart these new business models by funding the upfront costs, ABN AMRO did his for the FaaS case (Appendix I). By doing so, they not only support the adoption of more sustainable business models but also position themselves to benefit from the long-term cash flows generated by PSS. This could involve creating new financial products tailored to the unique requirements of PSS or adapting existing products to better suit these needs.

4.11 Start with a good BM

Embarking on a journey with a robust business model (BM) is an essential step towards a successful PSS The initial focus could be on developing a compelling value proposition and establishing a sustainable revenue model, as is done by Swapfiets (Appendix I). Once the BM proves its efficacy, it can then be steered towards circularity to further enhance its environmental and economic impact.

4.12 Convenience for clients

The case studies examined thus far underscore one common theme: clients are often willing to pay for the convenience and ease that a PSS offers. In each instance, the convenience factor has emerged as a significant driving force behind the customer's decision to opt for a PSS, even if it might not always be the most economical choice in the long run. In the case of Swapfiets (Appendix I), despite the financial calculation showing that owning a bike could be more economical over a period longer than two years, customers continue to favour Swapfiets. This preference for the leasing model over ownership is primarily driven by the convenience offered by Swapfiets. The service relieves customers from the responsibilities of maintenance and worries about theft or damage. The ease of subscription, the quality of the bikes, and the hassle-free replacement process add to the overall appeal of the service.

CHAPTER 5

PROPERTIES & CHARACTERSTICS

Chapter 5: Properties & Characteristics

While the factors influencing PSS form the context for their operation, the properties and characteristics of a product inherent to PSS play a significant role in determining their effectiveness and success. This chapter focuses on identifying and discussing these essential properties and characteristics that are integral to a robust and effective PSS. These can include aspects such as durability, repairability, (re-)usability, Customizability/ standardization, modularity, environmental sustainability and economic viability. Additionally, this chapter will address how these properties and characteristics can interact with the influencing factors discussed in the previous chapter. By doing so, the chapter aims to present a holistic understanding of what constitutes a successful PSS, providing valuable insights for organizations aiming to design and implement such systems.

There are many approaches to define a service, according to Weber et al. (2004) there is a problem between the definition of services and the material product. Because of the fundamental issue of the separation of service from physical objects, which is brought on by the inclusion of an outside component and the immaterial nature of a service.

Andreasen & McAloone (2008) describe a distinction between properties, which define how a product behaves and characteristics, which describe the composition and structure of a product. Characteristics can be directly impacted by the designer, the properties are often the result of those and not directly decided (Andreasen & McAloone, 2008). In this chapter the characteristics and properties, found in literature, that are needed for a product to function as a service will be defined. In figure 5.1 a model of PSS engineering from Weber et al. (2004) is shown. The relation between a products characteristics, properties, usefulness and customer control is made clear.

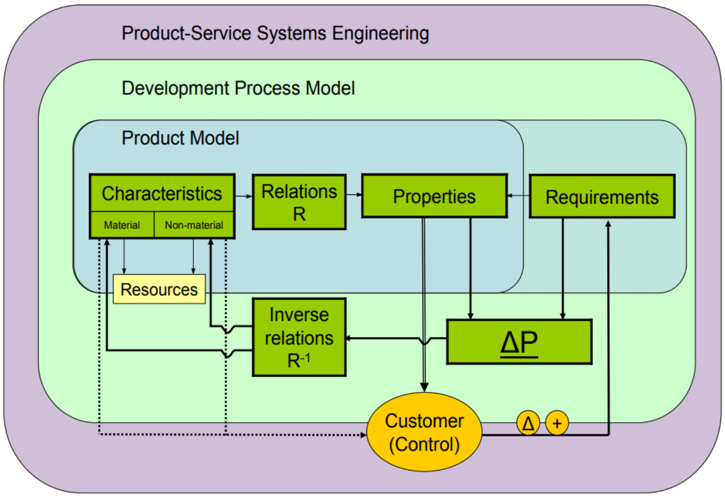

Figure 5.1: Model of PSS engineering (Weber et al., 2004)

5.1 Durability

Durability is a crucial property for PSS as it directly affects the life cycle of the product, which is a primary focus in PSS (Yang et al., 2010). A longer life cycle implies that the product can be utilized for an extended period, ultimately resulting in a higher revenue stream. On the contrary, a product subjected to intensive use would experience a shortened lifespan and an increased failure rate (Yang et al., 2010). Given that the implementation and operation of PSS are significantly influenced by customer behaviours and business processes are customer-centric, it becomes apparent that products with superior durability and extended lifespans form a key feature of PSS. These are likely better suited for use in a service setting.

However, using products with lengthy lifespans in a building also involves financial risks due to the potential for extended leasing contracts (Barykina, 2019). Hieminga (2015) asserts that contracts do not guarantee security in the event of a client or supplier's bankruptcy. Contracts are only as effective as the parties' adherence to them, and when bankruptcy occurs, the security provided by the contract is lost. As a result, longer lease contracts carry higher levels of uncertainty and risk. Consequently, service systems are typically better suited for shorter cycles, as the controlled duration of usage reduces the likelihood of problems or unforeseen events, making it easier to establish (contractual) agreements. Additionally, from a financial perspective, shorter cycles are more conducive to revenue models, as resources are returned to the provider more quickly.

In practice, this means that usage-oriented services (lease form) are generally employed for products with average lifespans of up to 10 years, product-oriented services (buy-back-purchase) for building products with longer life cycles, and result-oriented services (pay-per-use) for products with the shortest life cycles. Mohammedi and Slob (2016) note that services are predominantly provided for the usage of furniture and equipment.

Durability plays a significant role in the success of PSS in the built environment. The following points explain the importance of durability in PSS:

- Resource efficiency: Durable products in the built environment contribute to resource efficiency by reducing material consumption and waste generation. This aligns with the goals of PSS, which focus on creating value through sustainable resource management (Tukker, 2004).
- Reduced maintenance and replacement costs: Durable products require less maintenance and have a lower frequency of replacement, resulting in cost savings for both the service provider and the customer. This factor can contribute to the economic viability of PSS models in the built environment (Mont, 2002).
- Enhanced customer satisfaction: Durable products can lead to improved customer satisfaction, as they are less likely to fail or require replacement. This increased satisfaction can positively impact the reputation and long-term success of companies implementing PSS in the built environment (Rexfelt & Ornäs, 2009).
- Reduced environmental impact: Durable products in the built environment can minimize the environmental impact associated with the extraction, processing, and disposal of materials. This reduction supports the broader sustainability objectives of PSS models (Tukker, 2004).

To ensure the success of PSS in the built environment, companies must carefully consider the durability of their products and balance the potential benefits with the associated risks, such as financial uncertainty in long-term lease contracts (Barykina, 2019). The relationship with these factors is also shown in the conceptual model in figure 5.2.

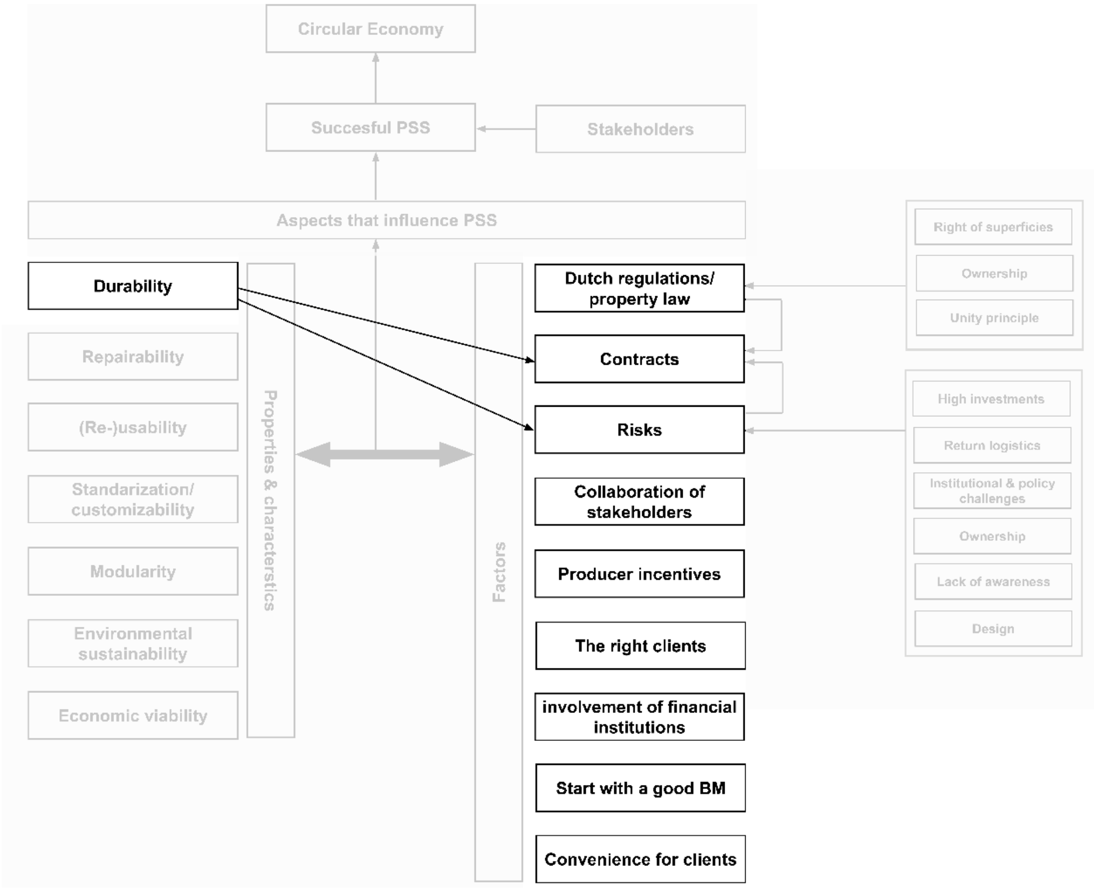

Figure 5.2: Relationship between durability and the different factors (own figure)

5.2 Repairability

Repairability is an essential property for PSS as it influences various aspects, such as the system's efficiency, sustainability, and profitability. Implementing PSS involves extended producer responsibility, which benefits suppliers when they adopt design and manufacturing strategies centred around easy maintenance and repair (Hieminga, 2015). Focusing on repairable products aligns with the goals of PSS, emphasizing value creation through sustainable resource management and extended product life cycles (Tukker, 2004).

Products that are easy to repair can decrease lifecycle costs for both providers and users. This reduction comes from minimizing the need for replacing items and lowering maintenance costs, thereby boosting the economic sustainability of PSS models (Mont, 2002). Another important facet of PSS is the integration of consumer feedback. This integration enables the creation of product service solutions that are attractive to the market and cater to customer needs (Parida et al., 2014). By refining their procedures for managing customer information, businesses can enhance their ability to access, gather, sort, and employ client feedback to address these needs.

Furthermore, repairable products in PSS contribute to the circular economy by promoting resource efficiency, reducing waste generation, and minimizing environmental impacts associated with the extraction, processing, and disposal of materials (Stahel, 2016). As a result, repairability is a critical property for PSS, enabling suppliers to maximize resource efficiency, reduce lifecycle costs, and ensure long-term profitability.

In the context of the built environment, building components that are easy to maintain and repair are likely better suited for use in a service. This compatibility is due to the PSS, which often involves businesses providing clients with ongoing maintenance and repair services. By focusing on repairability, PSS can thrive in the built environment, offering sustainable and cost-effective solutions that meet the needs of both suppliers and customers.

Repairability is intertwined with collaboration of stakeholders, contracts and convenience for clients, as shown in figure 5.3. Repairability requires a cooperative network of stakeholders, including manufacturers, service providers, and users. The process involves coordinating efforts to diagnose, fix, and verify the functionality of a product, which necessitates clear communication and collaboration among all parties involved. Repairability also significantly impacts the convenience for clients. Products designed to be easily repaired can minimize downtime, therefore reducing inconvenience for clients. The repairability of a product can be established within the contract with maintenance.

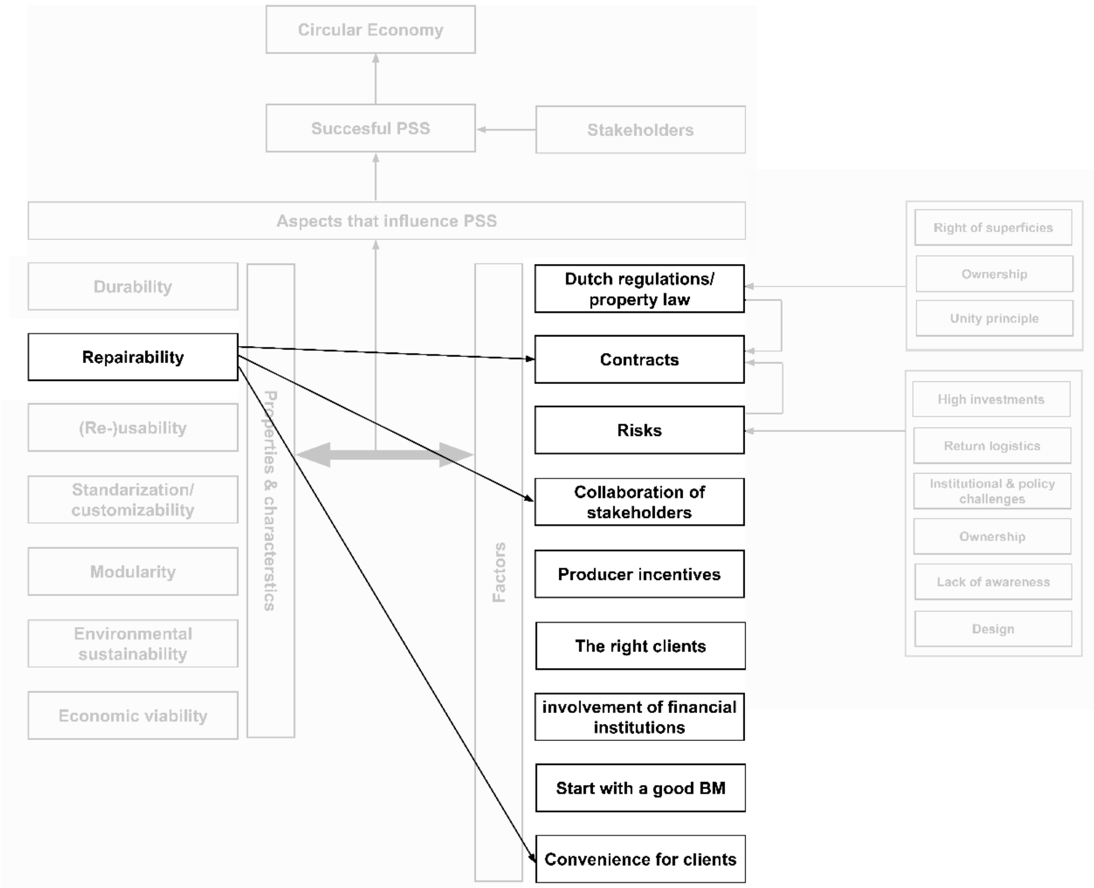

Figure 5.3: Relationship between repairability and the different factors (own figure)

5.3 (Re-)usability

Reusability is a critical property, as it directly impacts the system's efficiency, sustainability, and profitability. The concept of the "power of inner circle" introduced by the Ellen MacArthur Foundation (EMF, 2013a) highlights the importance of designing products for easy reusability, which implies that products should also be easily demountable. The tighter the circle, the less modification is required for reuse, refurbishment, and remanufacturing, allowing the product to return to use more quickly. This rapid return leads to larger potential savings on material, labour, energy, and capital embodied in the product, ultimately benefiting the supplier (EMF, 2013a).

Designing for reusability is a key aspect of the CE, which aims to optimize resource utilization and minimize waste generation (Stahel, 2016). Reusable products contribute to the economic viability of PSS models by reducing the need for new production, lowering lifecycle costs, and minimizing the environmental impacts associated with resource extraction, processing, and disposal (Tukker, 2004).

In the context of the built environment, products that are simple to operate and utilize are likely better suited for use as a service. The PSS model typically involves clients using the product on a frequent basis, and easier-to-use products may be more appealing to customers. By focusing on reusability, PSS can offer sustainable and cost-effective solutions that cater to the needs of both suppliers and customers, enhancing the overall success of the system.

In figure 5.4 the connection of (re-)usability is shown. (Re-)usability is strongly interconnected with collaboration of stakeholders, convenience for clients, and risks. (Re-)usability relies heavily on the cooperation of all stakeholders. An effective collaboration enables the optimization of product life cycles, with each stakeholder playing a role in ensuring the product can be effectively reused. The (re-)usability of a product has a direct influence on the convenience experienced by clients. Products designed for reuse should be easy to install, uninstall, and reinstall, thereby providing a seamless experience for clients. The connection with risks is also important, since there is a shift in ownership. (Re-)usability depends heavily on how the user of the product handles the product and moral hazard might be a problem.

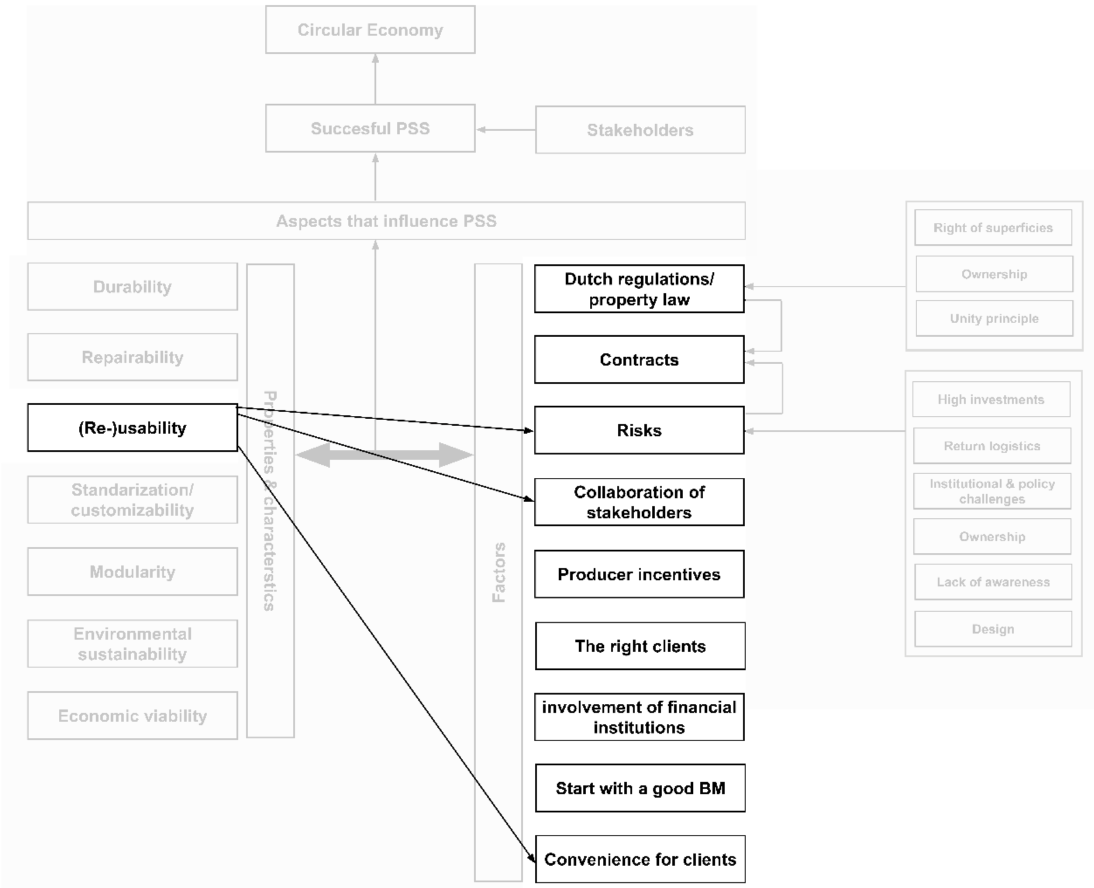

Figure 5.4: Relationship between (re-)usability and the different factors (own figure)

5.4 Customizability/ Standardization

Customizability and standardization are important characteristics (it concerns the structure of a product which can be directly influenced by the designer) as they contribute to the system's flexibility, adaptability, and efficiency. Song & Sakao (2017) state that customizable products can be better suited for use as a service, as the PSS approach often involves close collaboration with clients to meet their specific needs and preferences. This adaptability enables PSS providers to deliver tailored solutions that cater to diverse customer requirements, enhancing customer satisfaction and fostering long-term relationships (Baines et al., 2009).

However, products that are entirely or partially project-specific and custom-made can be part of more complex systems with varying life spans, creating challenges for demounting and reusing (Ploeger et al., 2019). The involvement of multiple service providers further complicates the process. In such situations, standardization plays a crucial role in facilitating reusability for other projects and reducing remanufacturing costs for suppliers. Standardized products enable easier integration into various systems, simplifying the maintenance, repair, and replacement processes (Perera et al., 1999).

Customizability and standardization are essential properties for PSS. Customizability allows providers to meet specific customer needs and preferences, while standardization ensures efficient integration, maintenance, and reuse of products across multiple projects. Finding the right balance between these two properties can significantly enhance the overall success and sustainability of a product service system.

Customizability/standardization has strong relationships with the factors right clients and risks as shown in figure 5.5. Custom-made products might increase operational complexities and costs, presenting a higher risk of production errors or customer dissatisfaction. On the other hand, standardization reduces these risks by simplifying operations and ensuring product consistency, but may not satisfy customer requirements. The level of customizability or standardization in a product must align with the needs and preferences of the targeted customer. Customers looking for unique, tailor-made solutions will value customizability, while those prioritizing cost-efficiency and reliability might prefer standardized products.

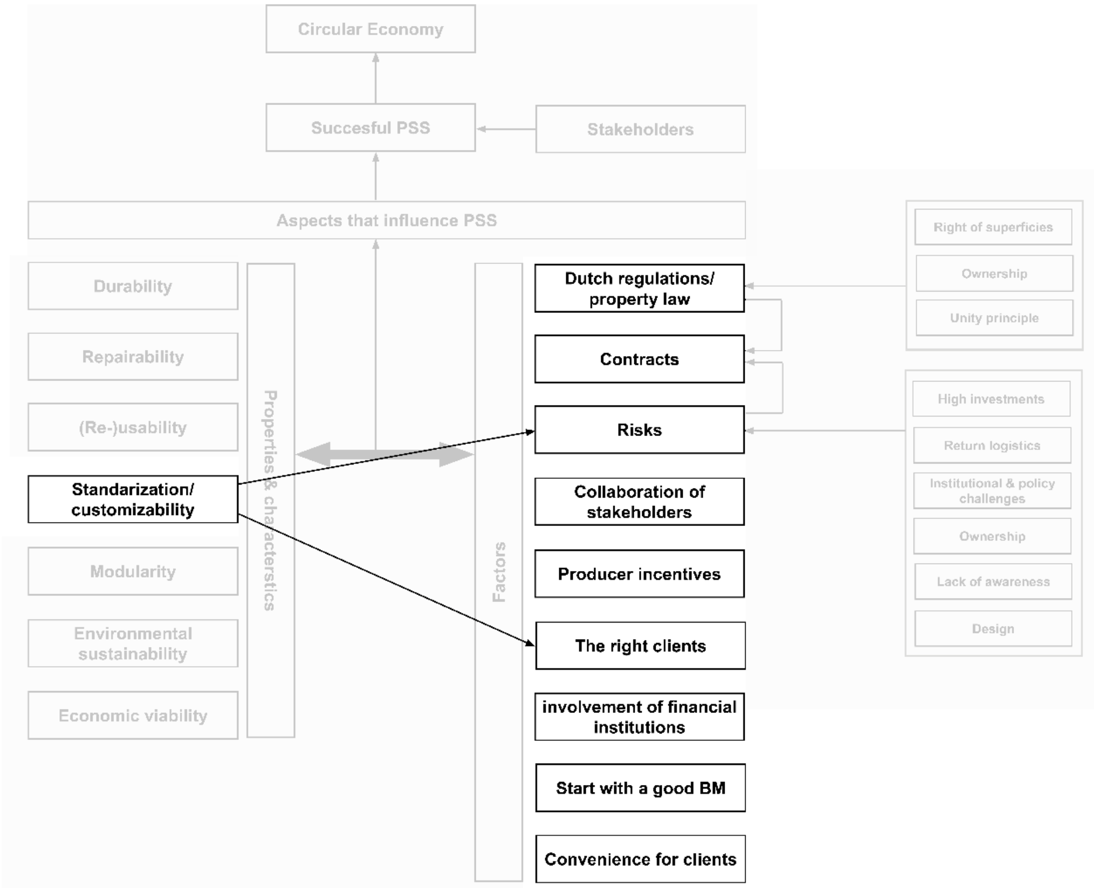

Figure 5.5: Relationship between customizability/ standardization and the different factors (own figure)

5.5 Modularity

Modularity is a characteristic (it's about the composition of the product, which the designer can directly influence), that refers to the design of products with interchangeable components that can be easily assembled, disassembled, and replaced (Baldwin & Clark, 2000). Modular products enhance the flexibility of PSS, allowing for easy maintenance, repair, and upgrade, thereby extending the product's life cycle and minimizing waste generation (Larsen et al., 2018). Modularity also supports customization, as different modules can be combined to create tailored solutions for various customer needs.

The characteristic of modularity shares significant interconnections with the factors: risks and the collaboration of stakeholders. Risks associated with modularity are increased complexity in design and manufacturing, and the potential for incompatibility between elements if not carefully managed. Therefor effective collaboration between stakeholders is essential to realize the benefits of modularity. The design, manufacturing, and usage stages need to be synchronized to ensure the modules can be seamlessly integrated and disassembled when required.

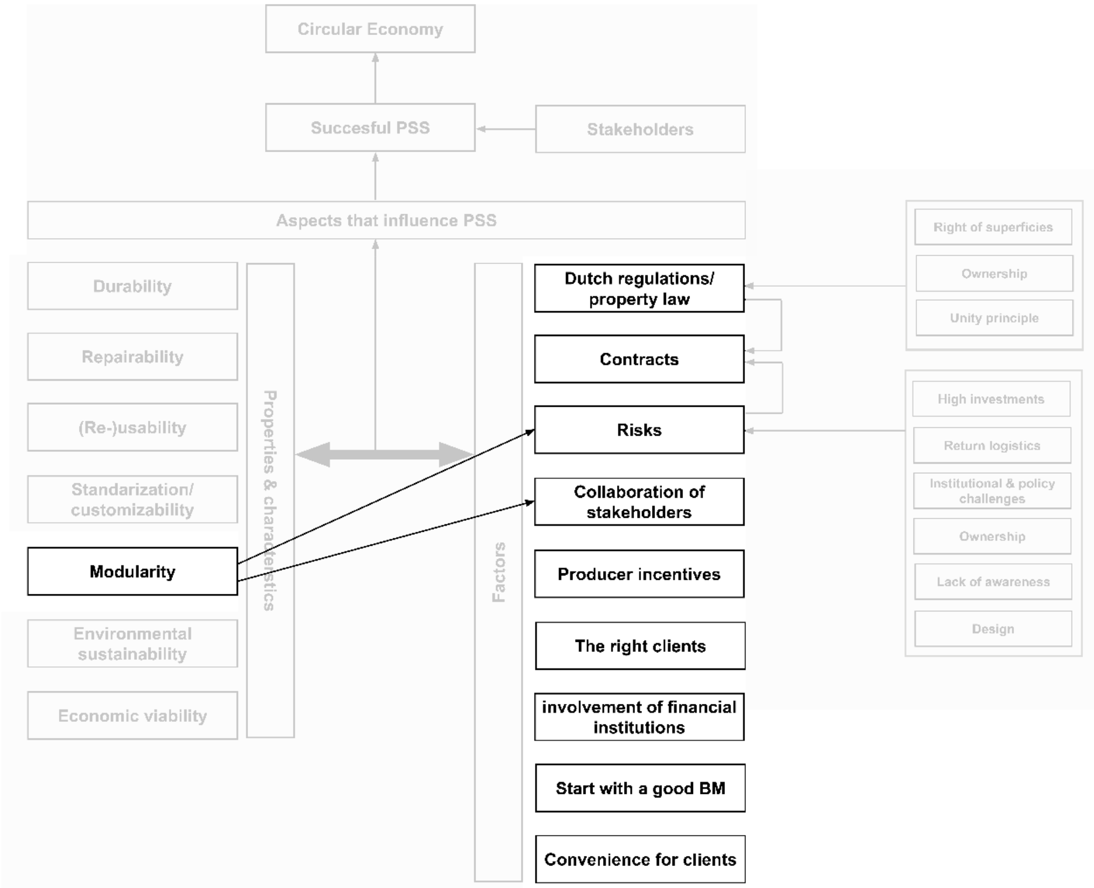

Figure 5.6: Relationship between modularity and the different factors (own figure)

5.6 Environmental sustainability

Environmental sustainability is a critical property of a PSS, particularly within the built environment. This property is a reflection of how the PSS behaves in its environmental context, an outcome derived from its inherent characteristics. The environmental sustainability of a PSS manifests in the system's ability to minimize environmental impacts at all stages: materials sourcing, manufacturing, transportation, usage, and disposal (Tukker, 2015).

When PSS providers incorporate eco-design principles and strategies from the circular economy, they position their systems to reduce their environmental footprint. This approach not only contributes to broader sustainable development goals but also resonates with the increasing demand for green solutions within the building sector. In this way, the PSS becomes an active participant in fostering environmental sustainability, demonstrating its responsibility towards the environment and society at large (Lieder & Rashid, 2016).

The characteristic of environmental sustainability significantly interacts with the factors risks and producer incentives. Environmental sustainability could introduce certain risks, such as economic, operational, or market related risks. The intrinsic motivation of the producer could play a crucial role in achieving environmental sustainability. Intrinsic motivation could be a personal or corporate commitment to reducing environmental harm.

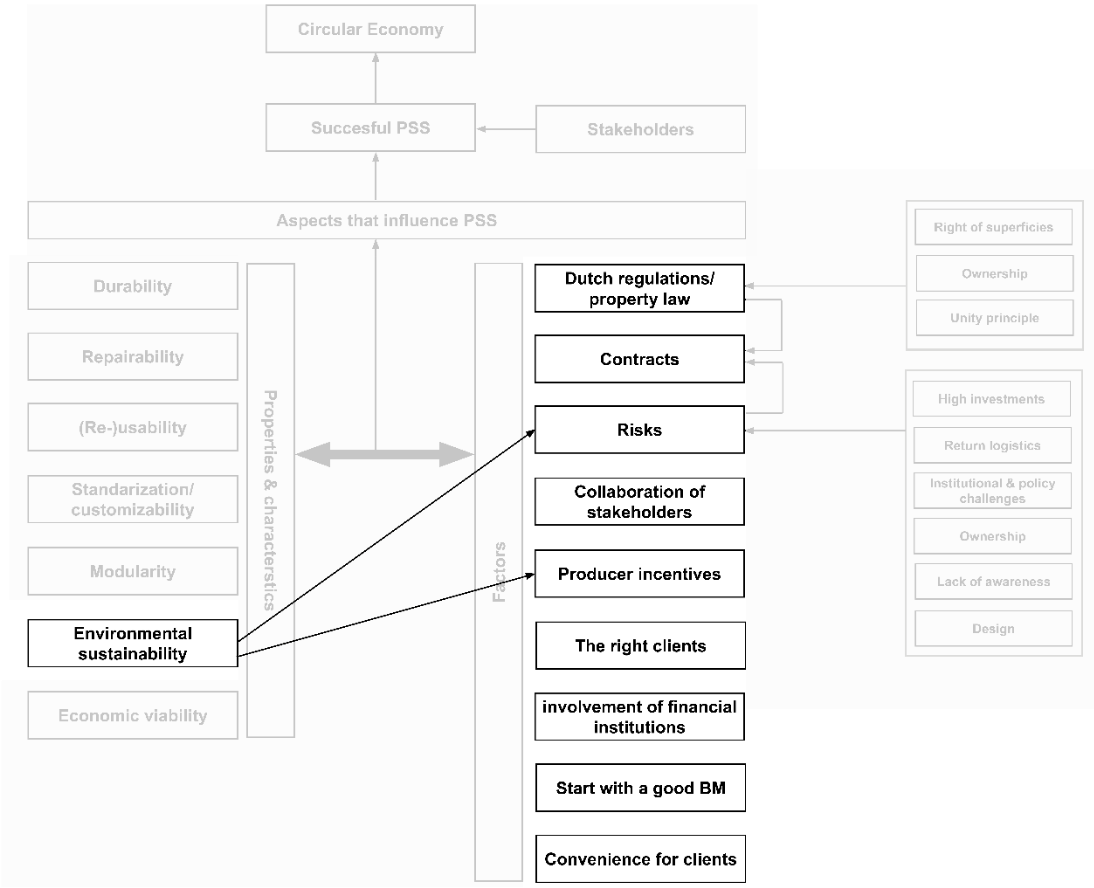

Figure 5.7: Relationship between environmental sustainability and the different factors (own figure)

5.7 Economic viability

As a property of a PSS economic viability describes the financial performance and sustainability of the system. It's important that the PSS proves financially beneficial to both providers and consumers to ensure its long-term success within the built environment (Tukker & Tischner, 2006). This means utilizing resources efficiently, reducing costs throughout the product's lifecycle, and establishing revenue models that equitably consider the interests of all involved parties. With an emphasis on creating and harnessing value, PSS providers can secure enduring profitability and maintain a competitive edge in the market (Baines et al., 2009).

The property economic viability is intertwined with the factors risks, the involvement of financial institutions, and a good BM. Economic viability is challenged by financial risks such as high upfront investment costs. These risks can threaten the profitability and sustainability of a PSS. The role of financial institutions can be instrumental in ensuring the economic viability of PSS. By providing capital and subsidies, these institutions can enable the producer to invest in necessary resources, manage cash flow, and navigate financial risks. A good BM is the foundation to the economic viability of a PSS. A well-planned BM can maximize profitability, ensure long-term sustainability, and adapt to changing market conditions.

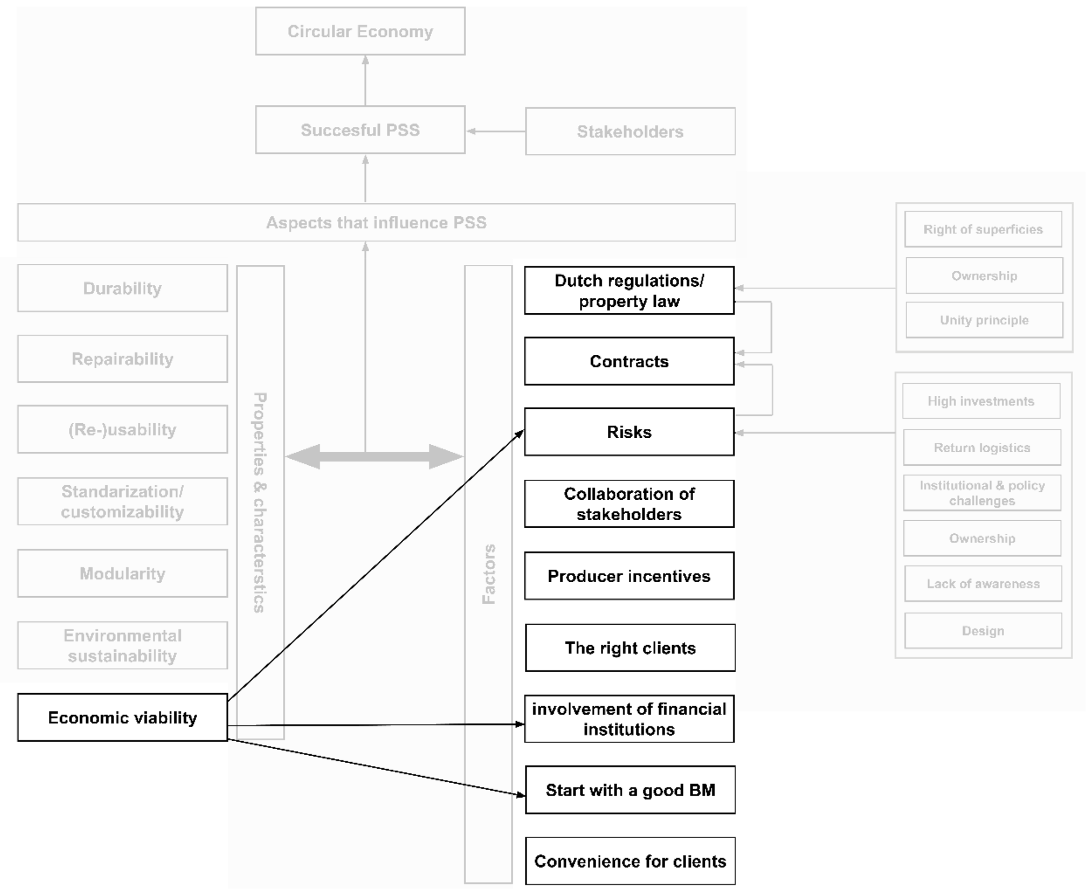

Figure 5.8: Relationship between economic viability and the different factors (own figure)

5.8 Lessons learned from existing PSS

The studied existing PSS also provided insights related to the product characteristics and properties that should be considered.

In the design phase of implementing PSS, we can derive critical insights from existing cases, as detailed in the Appendix I. The essential takeaways from these cases include: the importance of designing for misconduct, easy maintenance, acknowledging the design process as ongoing, avoiding welding and gluing for easier product dismantling, and implementing a feedback loop in design.

The façade design case demonstrates the use of a design feedback loop involving multiple stakeholders, resulting in enhanced building quality without significant upfront costs (Aguerre et al., 2019). In the Mitsubishi elevators case, strategies such as demount ability, material passports, and real-time monitoring were employed to improve circularity and extend lifespan (Mitsubishi, 2021; Zwart, 2018). Lastly, the Swapfiets bike design case highlighted the importance of adaptability and customer-focused design in improving efficiency and minimizing misuse (Niessen et al., 2022). These cases emphasize the necessity of a holistic approach to PSS design, considering technical, maintenance, and customer behaviour factors.

5.9 relationship between the properties & characteristics

This section discusses the interplay between various properties and characteristics. Figure 5.8 illustrates the intricate relations between these parameters. Durability contributes to (re-)usability, modularity and repairability, while also enhancing economic viability by prolonging product lifespan. Repairability facilitates (re-)usability and durability. (Re-)usability is interconnected with repairability and customizability/standardization as it requires adaptable designs to enable multiple use cycles. (Re-)usability also aligns with sustainability principles by minimizing waste.

Customizability/standardization plays a dual role, with standardization favouring modularity and economic viability due to streamlined production and compatibility, and customizability enhancing (re-)usability by adapting to specific needs. Modularity supports repairability, (re-)usability, and customizability by allowing component-level changes. Environmental sustainability is a holistic goal indirect influenced by all other parameters, while economic viability is necessary for any sustainable model to succeed in the long term. Together, these properties and characteristics provide a comprehensive view of the characteristics and properties a product needs to possess to become a successful PSS.

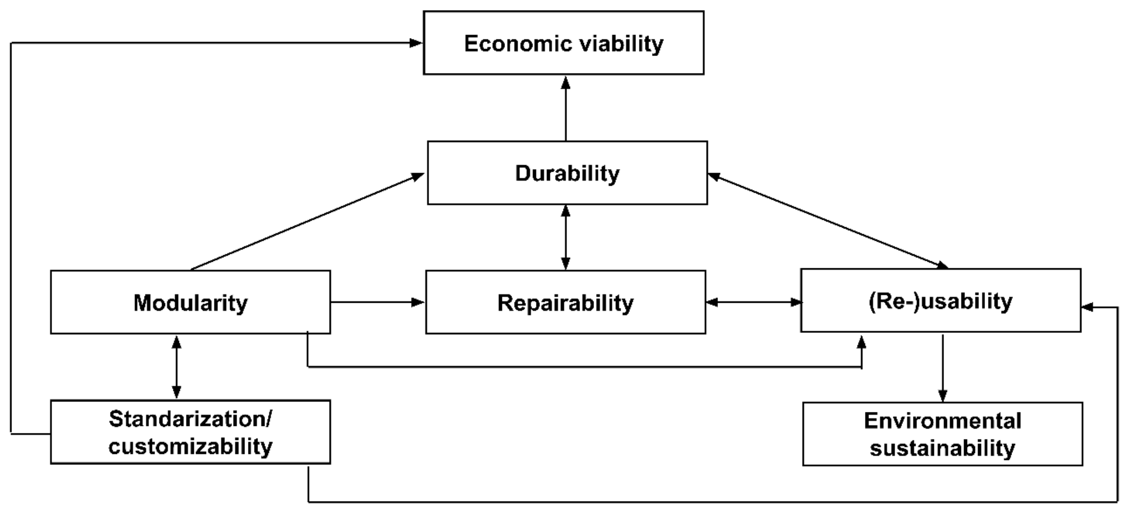

Figure 5.9: Relationship between modularity and the different factors (own figure)

5.10 The relationship between factors and properties & characteristics in existing PSS

This paragraph delves into the intricate interplay between the factors and properties & characteristics of an existing PSS: façade as a service (Appendix I). A comprehensive understanding of this relationship is instrumental in optimizing and scaling PSS for broader adoption in the built environment.

Figure 5.10 presents a detailed schematic representation of the 'Façade as a Service'. It highlights the integral elements involved in this specific PSS and maps out the interaction and interdependence between the system's key factors and properties/characteristics. The arrows in the figure denote the relationships between these factors and properties/characteristics.

The figure encapsulates the complex and interlinked ecosystem of the 'Façade as a Service' PSS, portraying how each component contributes to the PSS's functionality and ultimately, its potential for facilitating a circular economy in the built environment. It serves as a visual tool to understand the interconnected nature of PSS elements and how a harmonized alignment of these can lead to a successful and efficient PSS model.

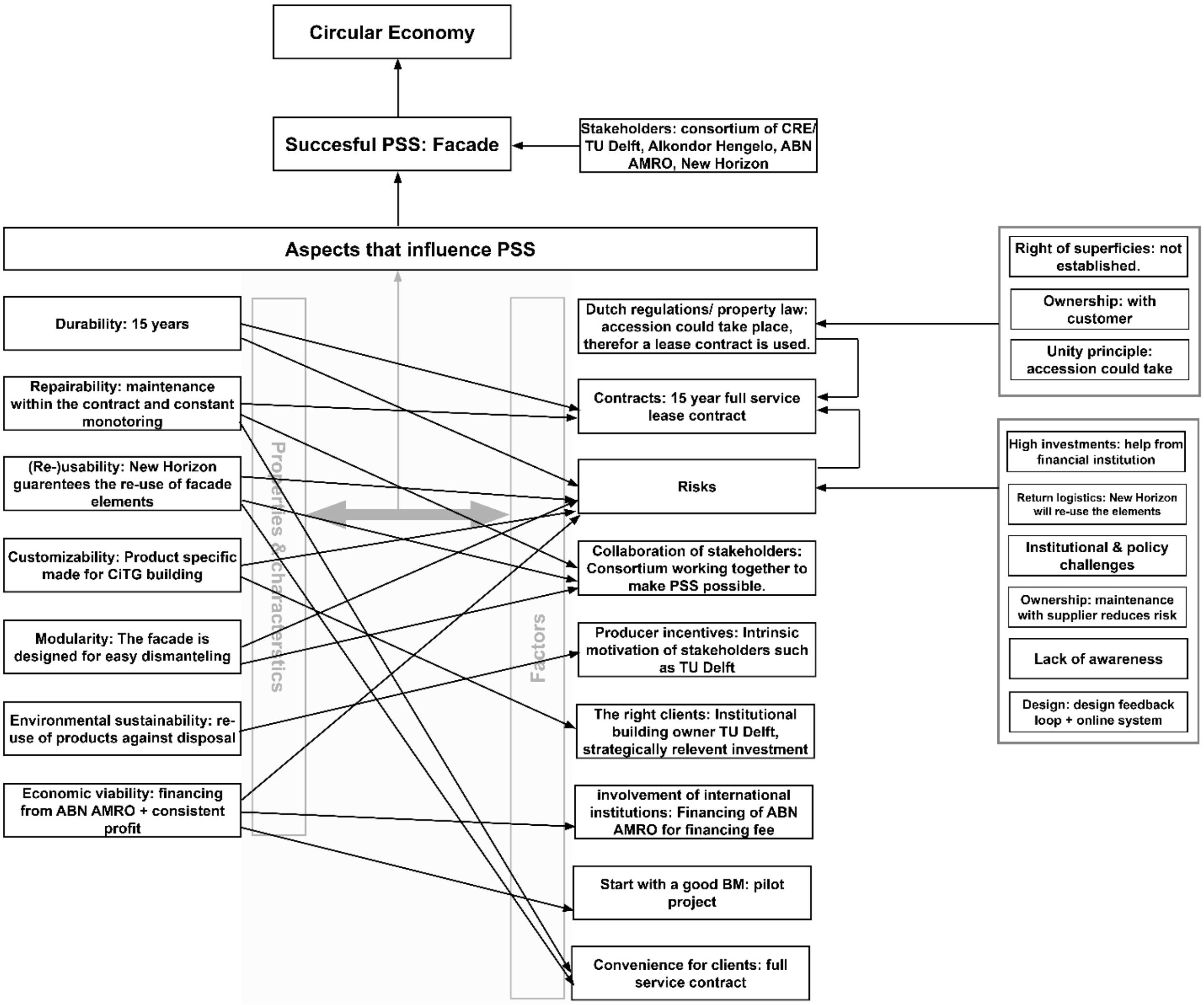

Figure 5.10: Relationship between properties/ characteristics and the different factors within façade as a service (own figure)

CHAPTER 6

PRODUCT SELECTION

Chapter 6: Product selection

To identify products that are possible for a PSS we need to identify products according to the right characteristics and properties found. An overview of al found characteristics in the literature is given in the figure below. The first column shows the aspect and the second column the explanation of that aspect which is a short summary of the findings in literature from the previous chapters. The third column indicates how that aspect will be analysed in figure 6.3.

Aspect	Explanation	Analysis of aspect for figure 6.3
(im)movable property	Immovable property means the land, unexploited minerals, vegetation united with the land, as well as the buildings and works permanently united with the land, either directly or by association with other buildings or works. Therefor the product should be movable. This refers to the ease with which building components can be transported and relocated without accession on the object taking place. The movability of a product can affect its suitability for a PSS in the built environment, with more portable products potentially being more suited for leasing and reuse.	This column checks whether the product is movable property (+), immovable property is indicated with a (-). This is determined on logic and the nature of the product. Is the product attached to land and how (permanently fixed?). Also what is the intention of attachment (intentionally permanent or not?)
Lease agreements	Lease agreements are contractual arrangements in which a provider retains ownership of a building component while granting the right to use it to a client for a specified period. Assessing the viability of lease agreements for different building components can help identify suitable products for PSS.	This column evaluates the product's potential to be leased or rented as part of a PSS model, (+) indicates that a lease agreement is possible. The possibility of the lease agreement depends on the financial feasibility and legal situation of the product and company. Therefor in theory lease contracts are possible for most products, but there needs to be a careful examination and professional legal guidance to ensure a legally sound and mutually beneficial arrangement.
Buyback/ take back schemes	In these arrangements, suppliers commit to taking back used building components from customers, either buying them back or accepting them for recycling, refurbishment, or remanufacturing. Analysing the feasibility of buyback or take-back schemes for different components can inform PSS implementation.	This column examines the product's potential to be part of a buyback or take-back scheme, where the manufacturer or supplier agrees to take back the product at the end of its life. A (+) indicates that this scheme is possible, however for this type of contract the same regulations apply as for leasing.
Right of superficies	Product might be an option to avoid an unintended transfer of ownership by accession and therefore no longer depend on a contractual obligation.	This column checks whether the product can be included in a right of superficies agreement, which grants the right to build or maintain a structure on another's land. Products like windows and dividing walls are marked as suitable for right of superficies (+). This column is filled in on logic and estimations, however professional legal advice is required to indicate the real suitability of each product.
Ownership	Understanding the legal and financial implications of owning building components is essential for developing a successful PSS. Examining different ownership structures can help determine which components are best suited for PSS.	This column assesses if the product is sensitive for accession. Products that have a risk for accession are less suitable for PSS and are indicated with (-), while products that are not at risks of accession are more suitable, indicated with (+).This

		column is filled in on logic and estimations, however professional legal advice is required to indicate the real suitability of each product.
Motive for producers	Assessing the financial incentives for implementing PSS can be crucial for determining its viability and identifying suitable building components. These motives can include cost savings, revenue generation, and risk mitigation.	This column assesses the financial incentives for implementing a PSS model for the product. Products with higher costs or potential for cost savings through shared use are marked with a high financial motive (high), while products with lower costs or less potential for cost savings are marked with a low financial motive (low). This column is filled in on logic and estimations, however for a more accurate overview a thorough investigation of each product and supplier needs to be done.
Investment costs	Analysing the initial investment costs associated with different building components can provide insight into their suitability for PSS. Components with lower investment costs might be more attractive for PSS implementation, as they can result in faster returns on investment.	This column indicates the initial investment costs required to implement a PSS model for the product from high – low. This column is filled in on logic and estimations, however for a more accurate overview a thorough investigation of the product and building costs needs to be done.
Return logistics	Evaluating the logistical aspects of returning building components after use, including transportation, storage, and processing, is essential for a successful PSS. Efficient return logistics can reduce costs, increase resource efficiency, and enhance sustainability.	This column examines the product's potential for implementing return logistics, which includes transportation, storage, and management of returned products. Products like windows and furniture are marked as suitable for return logistics (+). This column is filled in on estimation and logic; however, the return logistics depend strongly on the logistics of the supplier.
Design	Assessing the design features of building components, such as modularity, adaptability, and eco-design, can help identify products suitable for PSS. Components with favourable design characteristics can support PSS implementation by enhancing flexibility, durability, and sustainability.	This column evaluates the product's design, focusing on aspects like modularity, flexibility, and adaptability to facilitate the implementation of a PSS model. The more qualities the product possesses the better suitable for PSS (+). This column is filled in with common knowledge and logic of the product.
Durability	The lifespan and resilience of building components are crucial for PSS, as they can influence the profitability and sustainability of the system. Durable components can be used for longer periods, ultimately resulting in higher revenue streams and reduced environmental impacts. However the lifespan of the product in the BE is very important. Because the time of use is more controlled, short-cycle construction items are typically better suited for systems that are more service-oriented. As a result, it is simpler to come to (contractual) agreements because there is less chance of problems or unexpected developments. Also, from a financial perspective, short cycles are better suited to serve as the foundation for revenue	This column indicates the estimated lifespan of the product in years. The depreciation period is used from zlm Verzekeringen (n.d.).

	models as resources are returned to a provider more rapidly. A lifespan between 5-20 years would be sufficient.	
Repairability	The ability to maintain and fix building components is essential for a successful PSS. Components that are easy to repair can extend their lifecycle, reduce waste generation, and lower the total cost of ownership.	This column assesses the ease of repairing the product. Products that can be easily repaired, like windows and flooring, are marked as repairable (+). However, this column is filled in on logic and estimation. Every product could eventually be designed to become more repairable.
(Re-)usability	Reusability refers to the potential of building components to be used again in their original or an altered form, reducing waste and resource consumption	This column evaluates the product's potential for reuse, either in its current form or after refurbishment. Products like windows and dividing walls are marked as reusable (+). This column is filled in on estimations and the regularity the product is seen in second hand/ retail places.
Customizability/ standardization	Standardization refers to the uniformity of building components, simplifying integration and reuse. There should be a good mix of the customer being able to customize the product and standardization of the product.	This column estimates the product's potential for customization or standardization, which can impact the ease of implementing a PSS model. Products like windows and dividing walls are marked as customizable/ standardizable (+).
Modularity	The ease with which building components can be dismantled and removed from a structure affects their suitability for PSS. Demountable components can facilitate maintenance, repair, reuse, and recycling, contributing to a circular economy in the built environment.	This column checks whether the product is modular and can be easily demounted or disassembled, making it suitable for reuse or recycling. Products like windows and dividing walls are marked as demountable (+). This is determined by estimation of the current design of the product, however the designs of products can be adapted.
Environmental sustainability	The environmental impact across all stages. Incorporating eco-design and circular economy strategies, reducing environmental footprint, meet growing demand for green solutions, and contribute to sustainable development goals.	This column asses the environmental sustainability (+), while examining the environmental impacts of a product throughout its lifecycle, from raw material extraction and production to use and end-of-life disposal or recycling.
Economic viability	The products financial sustainability and performance. The PSS must benefit both providers and consumers financially, achieved through efficient resource use, lifecycle cost reduction, and fair revenue models	This column evaluates the financial feasibility of implementing a PSS model for a given product. A product is considered economically viable when expected financial returns outweigh the costs (+).

Figure 6.1: Summary of characteristics found in the literature (own figure)

6.1 Possible products

To identify possible products, multiple building components will be tested according to the different aspects found in the literature, as seen in figure 6.1. Researchers predict that the use of PSS in the building industry would eventually result into a “hull purchase” (Ploeger et al., 2015), where the purchaser of a building becomes the exclusive owner of the structure's hull: the structure, specifically its foundation, load-bearing walls, and roof. The owner then signs into a variety of "user agreements" for the inside of the building, which can include the kitchen, bathrooms and flooring. For some possible products a list is given if figure 6.2.

6.2 Analysing the products

In understanding the complex nature of PSS within the built environment, an extensive analysis of various products is necessary. This chapter critically analyses the comprehensive table provided in Figure 6.2, which includes a multitude of products associated with the built environment, from basic construction materials to more intricate systems and technologies. In the context of this analysis, it's essential to focus on attributes that define each product's suitability for a PSS framework, as shown in Figure 6.1. The attributes can be broadly classified into categories such as lease agreement, buyback scheme, investment costs, return logistics, design, durability, repairability, reusability, customizability, modularity, environmental sustainability, and economic viability.

Windows, doors, and frames, for instance, demonstrate notable adaptability to a PSS model, given their durability, ease of repair and reuse, as well as modularity. They, however, present medium investment costs and the ownership aspect is not straightforward (Bocken et al., 2016). Flooring and dividing walls also display similar trends.

Bathrooms, on the other hand, show a higher degree of potential for PSS remaining to the ease of maintaining ownership and their relatively high durability. Yet, their repairability and reusability are somewhat uncertain, adding a level of complexity to their inclusion in a PSS model.

Comparatively, bricks pose significant challenges to the PSS concept due to their lack of lease agreement and right of superficies, along with uncertainties in durability and reusability. Products such as roof tiles, corrugated plates, and gutters show mixed responses to a PSS framework, largely owing to the variability in their attributes, particularly the ease of ownership, investment costs, and return logistics. Complex systems like radiators, air conditioners, escalators, and boilers could be well-suited to a PSS model due to their higher value, longer lifespan, and potentially lower environmental impact if properly maintained and reused (Tukker, 2015). The same applies to emerging technologies such as smart building technologies, which also carry a higher initial investment cost but could be economically viable under a PSS model due to potential energy and cost savings.

Lastly, furnishings such as furniture, built-in packages, and kitchens provide unique opportunities for PSS implementation due to their high degree of customizability and modularity, but also pose challenges in terms of the ease of maintaining ownership and their economic viability.

The diverse set of products analysed provides a complex but insightful overview of the opportunities and challenges posed by implementing PSS in the built environment. The adoption of a PSS model can be beneficial from both an environmental sustainability and economic viability perspective, although the specific circumstances and attributes of each product must be carefully considered. In the following chapter a conclusion of the suitability of each product will be given.

PRODUCT	Movable property	lease agreement	right of superficies	buyback/take back scheme	Easy to keep Ownership	Financial motive	investment costs	return logistics	design	Durability (years)	repairability	(re-)usability	customizability/standardization	modularity	Environmental sustainability	Economic viability
Windows/ doors/ frames	+-	+	+	+	No	med	med	+	+	30/ 40	+	+	+	+		
Flooring	+-	+	+	+	No	Med	Med	+	+	10/ 20	+	+-	+	+		
Dividing walls	+-	+	+	+	No	Med	Med	+	+	-	+	+	+	+		
Bathrooms	+	+	+	+	yes	Med	Med	+	+	20	+-	+-	+-	+		
Fencing	+	+		+	yes	Low	low	+	+	15/ 20	+	+	+	+		
Bricks	-	-		+	No	Low		-	+		+-	+-	+-	-		
(Roof) tiles	+-	+		+	Yes /no	High	High	+-	+	50/ 80	+-	+-	+-	+		
(Roof) corrugated plates	+-	+		+	Yes /no	High	High	+-	+	30	+	+-	+-	+		
Gutters	+-	+		+	No	Med	Med	+-	+	20/ 30	+-	+-	+-	+-		
Radiators/ AC	+-	+		+	Yes	Med	Med	+	+	15	+	+	+	+		
Escalator	+-	+	+-	+	Yes	High	Med	+-	+		+	+	+-	-		
Staircases	+	+	+-	+	No	Med	Med	+-	+		+	+	+-	+-		
Drainage	+-	+		+	No	Med	Med	+-	+	20/ 30	+	+-	+-	+-		
Furniture	+	+		+	Yes	Low	Low	+	+	5/ 20	+	+	+	+		
Built-in package	+	+		+	No	High	High	+-	+		+	+	+-	+-		
Boiler	+	+		+	Yes	Med	Med	+	+	15	+	+	+	-		
Heat pump	+	+		+	Yes	Med	Med	+	+	15	+	+	+	-		
Thermostat	+	+		+	Yes	Med	Med	+	+	15	+	+	+	+-		
Pipework	-	+		+	No	High	High	-	+	40	+	+	+-	+		
Sun protection (in & out)	+	+		+	Yes	Med	Med	+	+	15	+	+	+	+		
Insulation material	+	+	+	+	No	High	Med	+	+-	20-50	+-	+	+	+		
Security systems	+	+		+	Yes	Med	Med	+	+	5-20	+	+	+	+		
Smart building technologies	+	+		+	Yes	high	High	+	+	5-20	+	+	+	+		
Kitchens	+	+			Yes	High	Med	+	+	10-20	+	+	+	+		

Figure 6.2: Overview of different products and evaluation (own figure)

Disclaimer: Please note that not all columns in the table are filled. This is due to either the information being currently unknown or not applicable to the context of the study. The gaps do not reflect an oversight but a current state of knowledge regarding the specific aspect under consideration.

Also as stated in the third column of figure 6.1 most of the columns are filled in on estimation and basic research. To create a good overview of the product is suitable for PSS a in depth research is necessary together with legal professionals with a supplier of each product.

For economic viability & environmental sustainability a more in dept analysis of the product should be done.

+ = good situation for PSS - = not a good situation for PSS

6.3 Suitability of the different products

Following the table in figure 6.2, this section delves deeper into the suitability of various products for PSS implementation. It is crucial to understand that not all products are equally agreeable with a PSS model. The suitability of a product for PSS is dependent upon several factors. This discussion brings forward the distinct characteristics and details of different products and their compatibility with the principles of PSS. The goal is to offer a nuanced understanding of the potential and challenges of implementing PSS across diverse product categories.

The suitability of products for PSS implementation is influenced by a multitude of factors, which have been encapsulated in figure 6.3. These factors range from design attributes, modularity, durability, repairability, reusability, and ease of installation and disassembly to legal and contractual arrangements, logistical considerations, and inherent limitations. However, it is crucial to note that the suitability assessment presented in figure 6.3 is based on a synthesis of estimations of information, derived from literature and document analysis, in conjunction with the product attributes discussed in Figure 6.2.

Building upon this exploration, the following table (in figure 6.3) is provided to illustrate the suitability of various products for PSS implementation in a clear, comparative manner. The table classifies products into three categories - "Suitable," "Potential," and "Not suitable" - based on their compatibility with the PSS model, considering their unique characteristics and inherent constraints.

> *In this context suitable refers to something that is appropriate or well-fitted for a particular purpose, context, or situation. Not suitable refers to something that is not appropriate or well-suited for a particular purpose, context, or situation. In terms of PSS, this means that a product does align/ or not align well with the PSS model. The term potential includes products that, while not inherently unsuitable, may require specific considerations or adaptations to function optimally within a PSS.*

Product	suitability	Limitations
Windows/ doors and frames	Potential	Design, legal and contractual arrangements, logistical considerations
Flooring	Potential	standardization and reusability, maintenance and repair costs
Dividing walls	Suitable	customization and integration of utilities
Bathrooms, Kitchens	Suitable	complexity of installation and integration with other building systems
Fencing	Suitable	
Bricks	Not suitable	heavy weight and the complexity of installation and disassembly
Gutters, radiators, A/C, escalators, staircases & drainage systems	Suitable	customization requirements and integration with other building systems
Furniture	Suitable	
Built-in package, boilers, heat pumps, thermostats, pipework	Potential	customization requirements and the complexity of integration with other building systems
Sun protection (in & out)	Suitable	
Insulation materials	Suitable	
Security systems	Suitable	
Smart building technologies	Suitable	

Figure 6.3: Products found and their suitability for PSS (own figure)

Products such as dividing walls, bathrooms, kitchens, fencing, gutters, radiators, A/C units, escalators, staircases, drainage systems, sun protection elements, insulation materials, security systems, and smart building technologies are deemed "Suitable". However, it is important to note that this suitability may be subject to customization requirements and integration with other building systems, which could potentially add complexity to the implementation of a PSS framework (Baines et al., 2007).

Conversely, bricks are classified as "Not suitable", primarily due to their heavy weight and the complexity associated with their installation and disassembly. Built-in packages, boilers, heat pumps, thermostats, and pipework have been categorized under "Potential", as their successful integration into a PSS framework requires careful consideration of customization requirements and the complexity of integration with other building systems.

To conclude most of the products have the potential to be suitable for a PSS in the Netherlands, depending on their design, modularity, ease of installation and disassembly, durability, repairability, and reusability. However, the success of a PSS for these components will depend on effective implementation, taking into account legal and contractual arrangements, logistical considerations, and the specific requirements of the built environment in the Netherlands. However to make sure that products are suitable for PSS pilot projects should be conducted.

CHAPTER 7

EMPIRCAL RESEARCH

Chapter 7: Empirical research

The insights obtained from the literature review are further explored through semi structured in-depth interviews with professionals in the field. This chapter presents the findings of these interviews and discusses the results. To ensure confidentiality, all personal information of the interviewees has been anonymized. Any quotations taken from Dutch-language interviews have been translated into English. Figure 7.1 provides an overview of the different interviews conducted.

Interview	Role
1	Investor
2	Supplier Kitchen
3	Supplier sun protection
4	Demolisher A
5	Supplier fencing
6	Demolisher B

Figure 7.1: Overview interviewees (own figure)

The interviews are held with the interview protocol in appendix II. The goal of the interview was to have discussion on the different topics with them and learning their opinions on the different measures. Also the reasons behind their choices were important and what risks and possibilities they thought were important for PSS. The interviews were transcripted and coded with atlas.ti. The codes used are shown in figure 7.2. Each code was assigned to relevant sections of the transcripts. These codes were then grouped into the following code groups:

- Contracts
- Design
- Existing PSS
- Financing
- Materials
- Mismatch of the market
- New possibilities
- Readiness of companies
- Regulations
- Risks
- Stakeholders
- Sustainability/ Circularity

The subsequent sections of this chapter will discuss each of these code categories in detail, highlighting the key findings from the interviews and relating them back to the insights gained from the literature review and case studies. This comprehensive analysis will contribute to a deeper understanding of the factors influencing the implementation of PSS in the built environment and identify potential areas for improvement and future research.

7.1 Codes per group

In order to analyse the interview data, a systematic coding process was applied to the transcripts. All transcripts were thoroughly examined, and relevant themes and talking points were assigned codes that were linked to specific text segments. This coding process enabled the organization and categorization of interview responses based on shared codes. As a result, responses with the same codes were grouped together, providing a clear overview of the participants who provided similar answers. This facilitated the comparison of results with each other and with the existing theoretical framework, thereby enabling the formulation of a convincing conclusion.

Additionally, the coding process also allowed for the identification of any contradictory answers, which could reveal interesting insights and opportunities for further research. The coding was conducted using the software program Atlas.ti, which generated a table, see figure 7.3, displaying the frequency with which each code group was mentioned.

Code group	Codes
Contracts	Abonnement on products; btb; buy back schemes; connection to other stakeholders; contracts; guarantees; lease agreements; maintenance; pay per use; rental; selling; take back of products
Design	Construction; demountable; design; fashionable; hull of the building; lifespan of product; long term; material passport; materials; modular building; new materials; no welding & gluing; repairability, wear and tear; standardization; state of the product; structural elements; technical
Existing PSS	Existing PSS
Financing	Abonnement on products; banks; buy back schemes; costs; financing; profit
Materials	Fashionable; material passport; materials; new materials; no welding & gluing; re-usability, recycling
Mismatch of the market	Awareness; banks; property-free society; customers; extended producer responsibility; feasibility; literature; logistics; material passport
New possibilities	Abonnement on products; property-free society
Readiness of companies	Extended producer responsibility; missing branch; feasibility; costs
Regulations	Dutch law; lease agreements; accession; ownership; public opinion; regulations; right of superficies
Risks	Costs; Dutch law; extended producer responsibility; financing; feasibility; high investments; fashionable; lease agreements; logistics; missing branche; modular construction; moral hazard; accession; ownership; regulations; repairability; risks; wear and tear
Stakeholders	Circular supply chain; connection to other stakeholders; customers; demolishers; investors; suppliers/producers
Sustainability/ circularity	Property-free society; biobased; circularity; cradle to cradle; demountable; innovations; modular construction; other circular measures; products as a service; re-usability; recycling; sustainable

Figure 7.2: Codes per group as input for Atlas.ti (Own figure)

7.2 Output

Following this explanation of the coding process, the subsequent paragraphs will delve into the results of each code group, highlighting the most important aspects identified by the interviewees.

CODE GROUPS *C = NUMBER OF CODES* *Q = NUMBER OF QUOTATIONS*	INTERVIEW 1	INTERVIEW 2	INTERVIEW 3	INTERVIEW 4	INTERVIEW 5	INTERVIEW 6	TOTAL
CONTRACTS **Q=77; C=12**	15	28	13	3	8	10	77
DESIGN Q=**74**; C=**18**	5	28	16	9	2	14	74
EXISTING PSS Q=**12**; C=**1**	8	3	0	0	0	1	12
FINANCING Q=**45**; C=**6**	16	14	9	0	4	2	45
MATERIALS Q=**46**; C=**7**	2	13	6	9	0	16	46
MISMATCH OF MARKET Q=**61**; C=**9**	5	27	14	1	5	9	61
NEW POSSIBILITIES Q=**14**; C=**2**	1	11	2	0	0	0	14
READINESS OF COMPANIES Q=**48**; C=**4**	10	12	14	2	4	6	48
REGULATIONS Q=**45**; C=**7**	14	24	3	0	2	2	45
RISKS Q=**104**; C=**23**	25	40	21	3	7	8	104
STAKEHOLDERS Q=**60**; C=**6**	8	23	14	1	3	11	60
SUSTAINABILITY/ CIRCULARITY Q=**81**; C=**13**	12	26	14	9	1	19	81
TOTALS	121	249	126	37	36	98	667

Figure 7.3: Code Analysis imported from atlas.ti (own figure)

7.2.1 Sustainability/ circularity

This code group had a relatively high number of quotations 81, with interviews 2 and 6 featuring the most extensive discussions. In each of the interviews it was mentioned that they think about sustainability measures, however the circularity measures were less taken into account. One supplier mentioned that they don't think about any sustainability measures, however another mentioned that they want to pioneer in this topic.

"The development on circular materials is something we are very much working on. So not using virgin materials. But using Circular materials, so recycled plastic. We are also working on bio-based materials to do something with that, so we are working very hard on that."- 2:9 Supplier Kitchens

"we do love innovation and pioneering as a manufacturer anyway". – 2:30 Supplier Kitchens

As seen in the co-occurrence table (in appendix V) circularity is often mentioned in relation to other topics, such as high investments needed to adopt a circularity strategy: "*But well to set up a whole* *circularity strategy with such a party. That just costs an enormous amount of money, if it's just a very big investment so we have refrained from going ahead with that for the moment. I don't want to say that we are ignoring circularity" – 3:16 Supplier Sun protection*

In one interview it was also mentioned that the they are willing to implement sustainable measures, but the client needs to be willing to pay for that: "*If we can deliver a very sustainable, beautiful green plus excellent Paris proof building, then of course we will do that, because that is also the client's demand in the end, but the client has to be willing to pay for it was." – 1:22 Interview investor*

7.2.2 Contracts

The code group contracts holds significance within all interviews. It has the second-highest number of total quotations (77). The topic was discussed in all interviews, with a particularly strong emphasis in interviews 2 and 3.

Interview 1 with highlights the potential financial challenges that companies face when transitioning from selling products to offering them as a service:

"That amount determines the lease amount you pay to the owner of the product, which you use as a service. But those companies just sold everything. So those companies will soon have a lot of trouble with their financing going forward." – 1:15 interview investor

The lease amount paid to the owner of the product becomes an important factor to consider when adopting a PSS model. This investor suggests that some companies may face difficulties in financing going forward. The interview also emphasizes the complexity and time-consuming nature of negotiating and maintaining a contract with PSS. In comparison to simply owning a building, the interviewee notes that managing maintenance plans and other contractual obligations can be more complicated.

In the second interview, the a supplier expresses scepticism about the feasibility of leasing a kitchen with a PSS model. The interviewee highlights the challenge of providing a producer obligation when the kitchen is not their property, suggesting that this obstacle may hinder the widespread adoption of leasing for kitchen products. However, they propose the idea of a deposit model as an alternative to traditional leasing. By offering customers money back for returning a product, the deposit model incentivizes users to be more mindful of their consumption and disposal habits:

"or you should work with a deposit model, say then you do keep remembering it, then you don't just throw it away if you know you will still get money back for it so then we could start working a kind of deposit model." 2:25 Interview supplier kitchens

In the fifth interview, the interviewee expresses a personal opposition to leasing:

"I personally am not a fan of leasing at all. No, I think, if you, or if you don't have the money, then you shouldn't buy it, I think, and otherwise just pay for it all at once." - 5:10 Supplier fencing

This perspective reveals that some stakeholders may have reservations about the PSS model, preferring traditional ownership instead.

7.2.3 Design & Materials

The design of products was also a significant topic, with the third-highest number of total quotations (74). The interviews with suppliers had the most substantial discussions on this topic. The demolishers mentioned that with the re-use of products it is important to take the trendiness and standardization of products is important:

"It is no longer trendy and according to the building code, for example, doors must have a certain height. Well, doors of the past are much lower than what doors are today. So they don't fit." – 4:4 interview demolisher 1

In interview X the supplier mentioned that for a product to be easier to re-use they also should be easy to demount and be future proof:

"We have to make our kitchens then on long-term use. We have to make it with material actually so modular that if we take it back, that we don't have too much refurbishment work. That should actually put it back in one-to-one. That would actually be the biggest strength of the product." – 2:21 Interview supplier kitchens

The materials of the products also got some attention in the interviews, mostly related to their design. Two of the suppliers mentioned that they are actively trying to use more sustainable materials:

"The development on circular materials is something we are very much working on. So not using virgin materials. But using Circular materials, so recycled plastic. We are also working on bio-based materials to do something with that, so we are working very hard on that." – 2:9 supplier kitchens

However the sun protection supplier emphasizes that while it is important to choose circular or more sustainable materials for a building, this should not compromise the building's functionality. In other words, the pursuit of environmentally-friendly materials should be balanced with maintaining or even enhancing the performance and usefulness of the building. The focus on better and more sustainable materials should go hand-in-hand with ensuring that the building continues to serve its intended purpose effectively.

7.2.4 Financing

Financing was discussed moderately throughout the interviews, with a total of 45 quotations. Interviews 1 and 2 had the most extensive discussions on this topic. This topic was an important topic in the interview with the investor, however this topic also held importance in the interviews with the suppliers. What was most discussed with this topic were the costs, costumers & lease agreements. In the following statements the importance of money is shown for these stakeholders.

"So yeah, just wondering: what does it get us? It costs you a lot in the first few years to invest since, because you actually have to pre-finance everything and how does that continue? I don't think I can just enter into a leasing contract as a company with an individual, I think. Then a credit check has to be done as well." – 5:11 Interview supplier fencing

"And I do kind of believe that we should do what we are strong at and that is producing kitchen cabinets and selling, designing and developing kitchens and I don't think we are in a party that should be running after our money if everyone is paying every month. So I don't think we will ever take up that independently, but always in collaboration with." – 2:38 Interview supplier kitchens

As mentioned in interview 3, it has to be feasible and therefor still many calculations have to be done.

If we do everything products, service, no, then you're not going to make it. But if you say: we, we offer the option and we look at the demand and based on that, we scale how much that's going to cost. Yes, then maybe we could, but it's actually it's not something that I don't think you can very easily estimate on the front end in terms of cost." – 3:24 Interview Supplier

7.2.5 Mismatch of market

This code group had a relatively high number of quotations (61), with interview 2 featuring the most extensive discussion. One of the concerns raised by the suppliers is the potential disconnect between legislation and the practical realities of implementing PSS:

“Often, legislation is thought up by people who are completely out of touch with practical situations and only know and understand a small part of the whole story. So that's one thing, that we as producers have to be very careful of, and that we are there early on and where we can tell our story and where we can have a say. We have to see to it that we actually do that, to make sure that no decisions are made that are simply not realistic or feasible.”- 2:57 Supplier kitchens

This highlights the need for effective communication and collaboration between the industry and policymakers to ensure that any new regulations are realistic and feasible for businesses. Another issue related to the mismatch of the market is consumer preferences. Some customers may not be interested in lease contracts or multiple payments, especially in the high-end segment. This suggests that for certain customer segments, PSS might not be an attractive option, and businesses need to consider these preferences when developing their strategies.

I think with us, customers are not waiting for that. I think, we are actually in high end. And those people who, yes, well, they pay with ease, so those people are not waiting for that. – 5:3 Interview supplier fencing

Creating awareness about the environmental impact of wasteful practices is also essential in promoting the adoption of PSS. Increasing awareness about waste and the benefits of PSS can help change consumer behaviour and encourage the adoption of more sustainable practices in the market.

“Otherwise, so much gets thrown away, huh, and everyone becomes very aware themselves that so much gets thrown away. Yeah, really ridiculous actually.” – 1:36 interview investor

7.2.5 Readiness of companies

The topic of the readiness of companies to adopt PSS has received moderate attention in the interviews. Although all interviewees acknowledged that PSS could be a positive development, as it would encourage suppliers to think more about re-use and sustainability of products, they also noted that there are still many obstacles to overcome.

One challenge is convincing and aligning the various stakeholders within an organization. As one interviewee from a sun protection company mentioned:

"But you also have to deal with other people within the organization, and you have to get them on board. You have to be able to convince them, reassure them, and make someone see the point of such an initiative" - 3:34 interview sun protection.

Another obstacle is the lack of resources and departments within companies to support PSS, particularly for smaller companies.

"Well, then we are just available as customer service, but there is not a service department that comes on site to fix things, for example. We are also currently not big enough to set up a whole department for that, those with service technicians and the like" - 3:3 interview sun protection.

"We are located throughout the Netherlands and Belgium. Then, I have to hire someone to just do that" (5:6 Interview fencing).

This highlights the need for companies to assess their readiness and capacity to adopt PSS before fully committing to this approach.

7.2.6 Risks & Regulations

Risks had the highest number of total quotations (104), indicating its importance in the interviews. The risks mentioned in the interviews are grouped together in the code group Risks. The most mentioned risks are: costs, Dutch law, extended producer responsibility, financing, feasibility, high investments, lease agreements, logistics, missing branch, moral hazard, ownership, regulations, repairability and the wear and tear of the product.

One risks mentioned by the suppliers is moral hazard, when leasing the product. There is no guarantee that the customer will handle the product with care. One supplier even mentioned that they might even be more reckless because it is not their own product.

Because it depends on both user. Yes, how do you say user behaviour as the type of product you purchase so if your product is yes call it what, if you buy a very wide size of blinds then that's the likelihood of that being error prone – 3:6 interview supplier sun protection

“Everything hinges on how user interacts with a kitchen.” – 2:47 Interview supplier kitchens

The ownership and regulations is also seen as an issue by the interviewees. One stated that: *It's all very difficult financially in terms of legislation* – (2:19 Interview supplier kitchens). They further elaborate on the difficulties with ownership when using PSS with kitchens.

“But the kitchen actually has a characteristic that it is firmly attached to a house. And that is as soon as the customer moves out, or he stops paying or whatever, you can't actually retrieve a kitchen so easily. Once it is fixed in that house, you actually have in terms of legal no claim.” – 2:14 Interview supplier kitchens

In the interview with the investor it was also highlighted the difficulties and uncertainties associated with the legal aspect of PSS, particularly in the context of financing and ownership. He stated if a bank finances a building, they would want to have a tangible asset as collateral. However, if the entire building is leased, it becomes unclear who the actual owner is, and who holds the mortgage rights to the property. This can create complications in case of bankruptcy, as the supplier of the leased materials might remove all assets from the building, leaving the bank without a tangible asset to secure their loan. The lack of clarity in ownership and rights can make it challenging for businesses and financial institutions to navigate the legal aspects of PSS.

7.2.7 Stakeholders

The role of stakeholders in a PSS received a moderate level of attention, with 60 total quotations across the interviews. Interviews 2 and 3 particularly focused on the significance of stakeholders in the implementation of PSS.

Interviewees acknowledged the interconnected nature of stakeholders in the PSS ecosystem. As the supplier of kitchens stated, "Ultimately, we are just a link in the chain, so we can facilitate a lot but would have to do some reckoning from the customer or actually be instigated" (interview supplier kitchens, 2023). This highlights the importance of cooperation and communication between various stakeholders to successfully implement PSS.

Furthermore, aligning the interests of different stakeholders within an organization is essential. An interviewee from a sun protection company emphasized, "But you also have to deal with other people within the organization and you have to get them on board. You have to be able to convince them, reassure them, and make someone see the point of such an initiative" (3:34 interview supplier sun protection, 2023).

Additionally, there is a lack of awareness among manufacturers about the end-of-life processes of their products. As one interviewee from a demolition company mentioned, "But I know a lot of manufacturers, or at least I usually talk to manufacturers, and they say: but what actually happens to my product, end of life? They don't even know what happens to it" (6:28 Interview demolisher 2, 2023).

Lastly, some manufacturers may fear that PSS implementation could lead to competition. The same interviewee from the demolition company pointed out, "The fear is also there with a lot of manufacturers that you become a competitor to them, because there's obviously going to be a very large amount released in their demolition project" (6:29 Interview demolisher 2). This underscores the importance of addressing stakeholders' concerns and fostering trust to ensure the success of PSS implementation.

7.3 Conclusion of interviews

In conclusion, the research has revealed that the adoption of a PSS model in the construction industry is a complex process involving multiple dimensions. These dimensions, including sustainability, contracts, design and materials, financing, mismatch of the market, readiness of companies, risks and regulations, and stakeholders' roles, are interconnected and affect each other in different ways.

Sustainability and circularity are recognized as important goals, but the interviews indicate that the emphasis is more on sustainability, with less consideration given to circularity measures. There is a clear need for more focus on circularity, including using recycled materials and adopting bio-based materials. However, the transition to circularity is perceived as costly, which can be a barrier to its adoption.

Contracts play a significant role in the PSS model, particularly in the transition from selling products to offering them as a service. There is a recognized complexity in negotiating and maintaining these contracts, including challenges with leasing arrangements and potential difficulties in financing.

Design and materials are significant factors in the potential for re-use of products. Standardization and trendiness of products are important, as well as the ability to demount products for future use. The use of sustainable materials is being pursued but must be balanced with ensuring the functionality and effectiveness of the buildings.

Financing is a considerable challenge in transitioning to a PSS model. Costs, customers, and lease agreements are all aspects of this challenge that require careful consideration and planning.

Mismatch of the market was noted as a potential issue, with some concern raised about potential disconnects between legislation and practical realities. Consumer preferences also play a role, with some segments potentially less interested in leasing arrangements.

The readiness of companies to adopt PSS is another aspect that requires consideration. There are numerous obstacles to overcome, including aligning various stakeholders within an organization and the lack of resources and departments within companies to support PSS.

Risks and regulations were the most frequently discussed topics, with issues related to moral hazard, ownership, and regulations seen as significant risks. There is a need for clarity in terms of ownership and rights when using PSS.

The role of stakeholders is crucial in the implementation of PSS. Cooperation and communication between various stakeholders are necessary for successful implementation, and aligning the interests of different stakeholders within an organization is also crucial.

In summary, the transition to a PSS model in the construction industry is a complex and multi-faceted process that requires careful planning and coordination among various stakeholders. While there are significant challenges to be addressed, including sustainability, contract management, design and materials, financing, market mismatch, company readiness, risks and regulations, and stakeholder roles, the potential benefits of PSS in terms of sustainability and circularity make it a worthy pursuit.

CHAPTER 8

DISCUSSION

Chapter 8: Discussion

Addressing the pressing need for a circular environment in the built environment, this study sought to explore new possibilities for future PSS. The aim was to consider all necessary characteristics, properties, and factors essential for the successful implementation of PSS within the built environment.

The results demonstrate that the built environment represents a significant area for the implementation of sustainable practices, particularly the application of PSS. Through an in-depth investigation, this research has revealed how PSS can be effectively applied in the built environment, thereby contributing to the transition towards a circular economy. A variety of internal and external factors were identified that influence the successful integration of PSS, including the legal environment, the contract structure, producer incentives, risks and stakeholder collaboration.

The findings indicate that certain properties and characteristics, such as durability, repairability, (re-)usability, customizability/standardization, modularity, environmental sustainability, and economic viability, are crucial for the optimal functioning of PSS. The research supports the theory that a multi-step approach is necessary for successful PSS implementation. This includes understanding the key factors, properties, and characteristics, selecting suitable products for PSS models, and assessing the readiness of companies and their stakeholders to integrate PSS into their operations.

By analysing various PSS implementations in practice, the study has contributed valuable insights into the practical aspects and challenges of PSS. The data suggest that stakeholders' increased awareness of the circular economy, along with mandated CE regulations, could serve as significant catalysts for widespread PSS adoption.

While this research has achieved its aim of exploring the potential for future PSS in the built environment, it also highlights the need for further in-depth investigations. The study confirms the potential of PSS in transforming the built environment towards a circular economy. However, the realization of this potential requires a concerted effort from all stakeholders to overcome identified barriers. This thesis thus provides a valuable starting point and a roadmap for future research and practical endeavours in implementing PSS within the built environment.

8.1 interpretations

The analysis and interpretations derived from this study offer a nuanced understanding of the essential factors, properties, and characteristics that contribute to the successful deployment PSS within the built environment. The complexity of determining the suitability of various products for a PSS model emerges as a significant insight, necessitating detailed, product-specific investigations. The interplay of multiple distinct variables introduces a level of complexity that renders the analysis of multiple products concurrently challenging, highlighting the need for comprehensive and individualized evaluations of each product under consideration for PSS adoption.

This study aligns with previous research, such as the work of Ploeger et al. (2019), in identifying the existing legal landscape in the Netherlands as a potential barrier to the large-scale adoption of PSS in the built environment. Current legal stipulations, particularly those concerning product accession, present a significant hurdle requiring thorough examination and potential revision to foster a more PSS-friendly legal environment.

Despite echoing the conclusions of previous studies in identifying the challenges to PSS implementation, this research endeavoured to go beyond these barriers in search of innovative solutions and advancement pathways. However, the findings confirm the existence of significant limitations to PSS implementation across various domains, such as legal frameworks, product characteristics, stakeholder readiness, and market acceptance.

Nonetheless, this study has illuminated potential areas for future research that hold promise in navigating these constraints. The focus areas include the development of capacity-building initiatives for stakeholders, policy adaptations, consumer education programs, and the leveraging of technological innovations. These insights serve as guiding posts, outlining the path towards a successful transition to a PSS model.

8.2 implications

The findings of this study offer a comprehensive view of the intricate facets of PSS providing key insights into the requisite conditions and variables necessary for their successful utilization in the built environment. These findings enrich the existing body of knowledge on PSS and their implementation in the built environment, contributing a granular understanding of the multiple, interconnected factors that affect the PSS model's feasibility and effectiveness.

These insights bear significant implications for various stakeholders, particularly those within the business community seeking to explore or implement PSS. By providing a thorough exploration of the characteristics, properties, and factors integral to a viable PSS, this research functions as a guide for businesses. It offers a foundation upon which to assess their products' suitability for a PSS model and, consequently, adapt their strategies accordingly.

Moreover, the legal implications and constraints identified by this research spotlight the necessity for legislative modifications to foster a beneficial environment for the adoption of PSS and broader circularity within the built environment. Legal professionals and policymakers could leverage these insights to articulate a case for law reform, addressing current restrictions and catalysing the movement towards a more circular and sustainable economy.

Therefore, this research both broadens the scholarly understanding of PSS implementation and offers tangible, actionable knowledge for practitioners in the field. The provided information contributes to theory, aligns with practice, and lays the groundwork for effective PSS implementation, ultimately underscoring the value and relevance of this research within the broader quest for a sustainable built environment.

8.3 Limitations of the Research

In conducting this study, several limitations were encountered, which should be taken into account when interpreting the findings. Firstly, the scope of data collection was relatively limited. Only seven interviews were conducted, restricting the depth and diversity of insights gathered. An expanded scope, including a wider range of stakeholders within the circular supply chain of each product examined, particularly the producers and suppliers, would provide a more robust and nuanced understanding.

Further, while the research covered a range of products for potential PSS implementation, a more in-depth exploration of each product's specific characteristics, requirements, and life cycles was not conducted. This approach might have limited the specificity of the findings related to each product's suitability for PSS. An alternative research approach focusing on a single product might yield a more precise and detailed understanding of what is necessary to transform that product into a PSS.

The absence of pilot projects for each product also represents a limitation. Pilot projects could provide invaluable practical insights and identify potential challenges and solutions, contributing to the richness of the research findings.

Another notable constraint was the lack of investigation into market acceptance of PSS. The willingness of producers and customers to adapt to PSS is a crucial factor for its successful implementation and was not thoroughly examined in this research.

Despite these limitations, the research contributes to the understanding of the conditions and factors necessary for PSS implementation in the built environment. It provides a starting point for further research and explorations in the field, emphasizing the need for comprehensive, in-depth studies that incorporate a wide array of perspectives and data sources.

8.4 Recommendations for further research

Detailed, product-specific research would significantly enhance the understanding of the potential suitability of different products for PSS in the built environment. Implementing pilot projects for each product category could yield practical insights into the challenges and opportunities associated with each product's PSS transformation. This could emulate successful examples like the 'Facade as a Service' project conducted by TU Delft.

An in-depth examination of the legal framework, particularly Dutch regulations relating to product accession, is another key area warranting further investigation. Collaborative research with legal experts could yield insights into potential legal hurdles and strategies to overcome them, contributing to an environment more favourable to PSS implementation.

Exploring the potential role of technological advancements, such as IoT and AI, in facilitating PSS could also prove beneficial. Such investigations could illuminate how these technologies might improve product maintenance, usage tracking, and overall service delivery in the context of PSS.

Lastly, an expanded economic analysis would add value. A comprehensive understanding of the economic implications associated with transitioning to PSS, including potential impacts on job markets, skills requirements, and broader economic dynamics, is critical to developing well-rounded PSS strategies.

This study has opened avenues for contributions to both societal and scientific communities. In societal contexts, the research findings could assist policy makers, industry leaders, and consumers in navigating the challenges of transitioning to PSS. This could support the fostering of a more sustainable built environment. Meanwhile, from a scientific perspective, this study adds to the growing body of knowledge surrounding PSS in the built environment, laying a foundation for further exploration and practical applications.

CHAPTER 9

CONCLUSION

Chapter 9: Conclusion

This study delved into the exploration of Product-Service Systems (PSS) within the built environment in the Netherlands, focusing on the promise of PSS to foster circularity and sustainability. The main research question guiding this investigation was: *"How can Product-Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?"* This is broken down into several sub-questions. In this concluding chapter, the main research question will be addressed, integrating the findings from each of the sub-questions.

9.1 What is circularity in the built environment?

Circularity within the built environment represents a paradigm shift from traditional linear economic models to a more sustainable, circular approach. The linear model, an entrenched economic theory, is predicated on the "take, make, use, dispose" principle. This model embodies the extraction of resources, their transformation into goods, consumption, and eventual disposal as waste, following a linear trajectory. Historically, this model has supported economic growth, largely due to declining real resource prices and low waste disposal costs. However, it has also resulted in substantial resource wastage and environmental degradation, posing significant risks to the stability of global economies.

The circular model or circular economy provides an alternative, with the potential to revolutionize how we manage resources in the built environment. This model focuses on minimizing waste and maximizing resource utilization, aiming to create a closed-loop system where resources are continually used, recovered, and regenerated rather than being discarded as waste. This approach emphasizes the need for a "functional service" perspective, which fosters the development of more durable products and encourages product-service transitions when appropriate. The circular economy is underpinned by three key principles: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature.

Applying circularity to the built environment involves implementing strategies such as using sustainable materials and technologies, designing for reusability and adaptability, and encouraging resource-conserving behaviours. It offers significant benefits including reducing ecological and carbon footprints, supporting economic growth, and contributing to the development of more liveable and resilient communities. Notably, the built environment offers vast opportunities for implementing new business models, such as PSS to further promote circularity.

A crucial component of a circular economy is the circular supply chain, which aims to maintain materials, components, and products at their optimum utility and value over time. This involves creating closed-loop systems where waste products and by-products are reused, recovered, and recycled, extending the life of resources. Key guiding principles for the development of a circular supply chain include designing products for circularity, changing resource demand patterns, fostering collaboration among stakeholders, and introducing new business models that facilitate the transition from linear to circular systems.

In conclusion, circularity in the built environment, as underpinned by the circular economy and circular supply chains, offers a sustainable and resource-efficient alternative to traditional linear models. This shift necessitates a collective effort across various sectors, including the built environment, towards designing for durability, maximizing resource use, minimizing waste, and fostering collaborations across supply chains. Ultimately, embracing circularity is a pivotal step towards creating a more sustainable future.

9.2 What are product service systems in the built environment?

PSS in the built environment represent an innovative approach that integrates products and services, providing significant value to customers and addressing their needs while concurrently aiming to reduce environmental impacts and resource consumption. This model, which moves away from the traditional concept of ownership towards a system of access, use, or performance-based agreements, opens up new revenue streams for companies, enhances customer relationships, and contributes to sustainability objectives.

Within the built environment, the use-oriented PSS, where products are supplied to customers without transferring ownership, is particularly relevant. Companies offer products as services rather than selling the product outright, allowing customers to enjoy the benefits of the product without the requirement of full ownership. This approach extends the lifecycle of products, reduces waste, and promotes the reuse and repurposing of products, thereby fostering circularity.

However, the transition to a PSS model does not automatically guarantee reduced environmental impact. This outcome depends on the specific design of the system and the behavioural changes of consumers. The realization of circularity is greater in result-oriented PSS, where the producer retains ownership and is motivated to create a system with a lower impact on resource and energy efficiency.

A key tool in achieving the sustainability objectives of PSS in the built environment is the life cycle assessment (LCA). Recognizing the importance of "cradle-to-cradle" material flow, the LCA provides invaluable insights into designing products for continuous recovery, ensuring that PSS models contribute effectively to the realization of a circular economy.

Conclusively, while PSS offers a promising pathway towards circularity and sustainability in the built environment, its effective implementation depends on a variety of factors, including the specific design of the PSS, the behavioural changes of consumers, the type of PSS (use- or result-oriented), and the application of tools like LCA. Further research and practice will be instrumental in refining PSS models and enhancing their contribution to the circular economy.

9.3 What is the importance of the stakeholders within the circular chain of product service systems?

Stakeholders are essential to the successful implementation of PSS in the built environment. Producers/ suppliers have expanded roles beyond product creation, involving them in the product's entire lifecycle, including reuse, recycling, and customer education. This involvement fosters innovation and market responsiveness. Users are at the heart of PSS. Their feedback informs the development process, helping businesses understand and shape customer demands, thus providing more options and reduced costs for customers. Governmental parties shape the regulatory environment affecting PSS. Their role in defining property laws and making regulatory adjustments is crucial for facilitating PSS in the built environment.

The successful implementation of PSS in the built environment relies on a network of stakeholders, each playing a distinct yet interconnected role. From product creation to end-of-life management and from customer engagement to regulatory shaping. Stakeholders are instrumental in driving the shift towards a more circular economy. Their collaborative efforts can lead to more resilient, sustainable, and innovative PSS models.

9.4 What factors influence product service systems?

Several factors influence the implementation and success of PSS in the built environment, such as Dutch law, contracts, producer incentives, risks & the collaboration of stakeholders.

Current Dutch property law presents challenges for the establishment of PSS due to legal concepts such as accession, unity principle, and common opinion. These concepts obstruct resource sharing and modular design, which are key elements of a circular economy. Additionally, current common opinion and property laws lack the necessary adaptability to support circular trading relationships and innovative, resource-efficient approaches. However, as circular practices become more prevalent in industries like construction, these traditional perspectives may shift, potentially requiring legal framework adaptations to better support PSS and circular business models. There is a need for legal adjustments to facilitate the adaptation of a circular economy. Researchers suggest that the Dutch property law, particularly the civil code, needs to be revised to align with the principles of a circular economy. Despite these challenges, potential solutions include employing lease agreements with penalty stipulations and advocating for changes in legal frameworks to support circular trading relationships.

Implementing PSS requires well-structured contracts that address the unique characteristics of the circular economy. Retaining ownership of building parts can introduce legal uncertainties, thereby hindering the development of circular business models. Contracts need to clearly allocate responsibilities and liabilities among parties involved in PSS. Different types of PSS require different contract types, emphasizing the need for clarity in contractual frameworks. Contracts such as leasing, pay-per-use, and take-back and buy-back agreements can facilitate the implementation of PSS. These models help manage cash flow, mitigate financial risks, and incentivize suppliers to repurpose their goods in the next cycle. However, their feasibility largely depends on the reputability of the customer or reduction of income stream risks for funders.

Producer incentives, such as the profitability can promote the adoption of PSS. Financial incentives are crucial for producers to adopt new, reuse-focused revenue models, thereby promoting circularity.

The adoption of PSS comes with inherent risks for stakeholders, including high initial investments, design challenges, and logistical, institutional, and policy obstacles. It's critical to understand these risks for stakeholders to effectively strategize for PSS adoption. Also the collaboration and effective communication among all stakeholders are essential for successful implementation of PSS. According to Leising et al. (2018), a five-step tool that includes co-creation, multidisciplinary teams, trust-based contracts, collective business models, and planning for product reuse can foster collaboration and promote a functional circular economy.

In conclusion, the successful implementation and operation of PSS in the built environment depend on a multitude of factors, including the legal environment, contract structure, financial models, incentives for producers, risks mitigation, and collaboration among stakeholders. As the potential of PSS for sustainability and circularity is recognized, strategies addressing these factors become increasingly important.

9.5 What are the characteristics & properties necessary for product service systems?

The effectiveness and success of PSS hinge on the product's inherent properties and characteristics. Durability and repairability are key properties, influencing the product's lifecycle, revenue generation potential, and overall system efficiency. Durable products are ideal for PSS due to their extended usability and potential to generate revenue over longer periods. Simultaneously, products that are easily repairable can lower lifecycle costs by minimizing replacement and maintenance expenses, thus contributing to the economic viability of the PSS model.

Moreover, reusability directly affects the sustainability and profitability of the PSS. A design focusing on easy demount ability reduces the need for new production, minimizes lifecycle costs, and decreases the environmental impacts associated with resource extraction, processing, and disposal. Customizability and standardization also play crucial roles. Customizability enhances customer satisfaction by delivering tailored solutions, while standardization facilitates reusability and cost reduction for suppliers.

The concept of modularity, where products are designed with interchangeable components, offers additional flexibility, facilitating maintenance, repair, and upgrade processes while supporting the creation of bespoke solutions. Environmental sustainability, reflecting the PSS's capacity to minimize environmental impacts across all stages, is also a critical property. The economic viability of the PSS, which describes its financial performance and sustainability, is essential to ensure the system's longevity. Both providers and consumers must find the PSS financially beneficial for it to be successful in the long term.

In essence, these properties and characteristics form the backbone of a successful PSS in the built environment, collectively influencing its performance, sustainability, and profitability. Therefore, striking a harmonious balance among these aspects is vital for a PSS's success.

9.6 What are the future possibilities for product service systems in the built environment?

The future of PSS within the built environment presents a multitude of opportunities. This future is rich with potential, as various building components can be adopted into the PSS model. Through comprehensive analysis and testing of multiple components, it is anticipated that the building industry may shift towards a "hull purchase" model. In this model, the owner procures exclusive ownership of the building's shell, inclusive of its foundation, load-bearing walls, and roof, while entering "user agreements" for the building's interior components such as kitchens, bathrooms, and flooring.

A broad range of building components have been analysed in this study, each varying in complexity from basic construction materials to sophisticated technologies. This comprehensive examination provides an extensive evaluation of potential products for PSS implementation within the built environment. However, it must be noted that not all products are equally suitable for PSS. The compatibility of a product with the PSS model depends on various factors. These include design, modularity, ease of installation and disassembly, durability, repairability, reusability, and specific legal, contractual, and logistical considerations. Based on these factors, products can be classified into three categories: "Suitable," "Potential," and "Not suitable" for PSS application.

The majority of components show promise for PSS applicability within the built environment in the Netherlands, provided they can be successfully implemented, considering the factors mentioned above. However, to confirm this suitability, it is suggested that pilot projects be executed to trial and validate these components within the PSS model. Therefore, the future of PSS within the built environment relies on rigorous exploration, informed decision-making, and adaptable implementation.

It must be recognized that the future potential for PSS in the built environment is vast but complex, demanding careful consideration of numerous intertwined factors. In discussions with experts, it became clear that several dimensions are linked, each affecting and being affected by the others. These dimensions include sustainability, contracts, design and materials, financing, market mismatch, readiness of companies, risks and regulations, and stakeholder roles.

For PSS to be adopted successfully, the industry must balance the emphasis on sustainability with a focus on circularity, despite potential financial challenges. Additionally, contractual complexities and choices in design and material present further hurdles to PSS adoption. Financial challenges are another area of concern during this transition, as potential market mismatches, determined by legislation, practical realities, and consumer preferences, must be tackled.

The readiness of companies to adopt PSS and the need to mitigate risks and regulatory uncertainties are crucial for successful implementation. Furthermore, stakeholder roles are pivotal, with effective communication and interest alignment being key factors. Despite these challenges, the potential benefits of PSS, particularly in terms of sustainability and circularity, render it a promising endeavour for the building industry.

9.10 Research question: How can Product Service Systems (PSS) be applied in the built environment and expanded to their fullest potential?

In conclusion, the application and expansion of PSS within the built environment hinges on a multi-faceted approach that addresses both inherent and external factors.

To begin with, understanding the key influencing factors is essential. As seen in Figure 9.1, a range of elements covering the legal environment, contract structure, financial models, incentives for producers, risk mitigation, stakeholder collaboration, a robust business model, financial institution involvement, and client convenience, all critically impact the implementation and success of PSS.

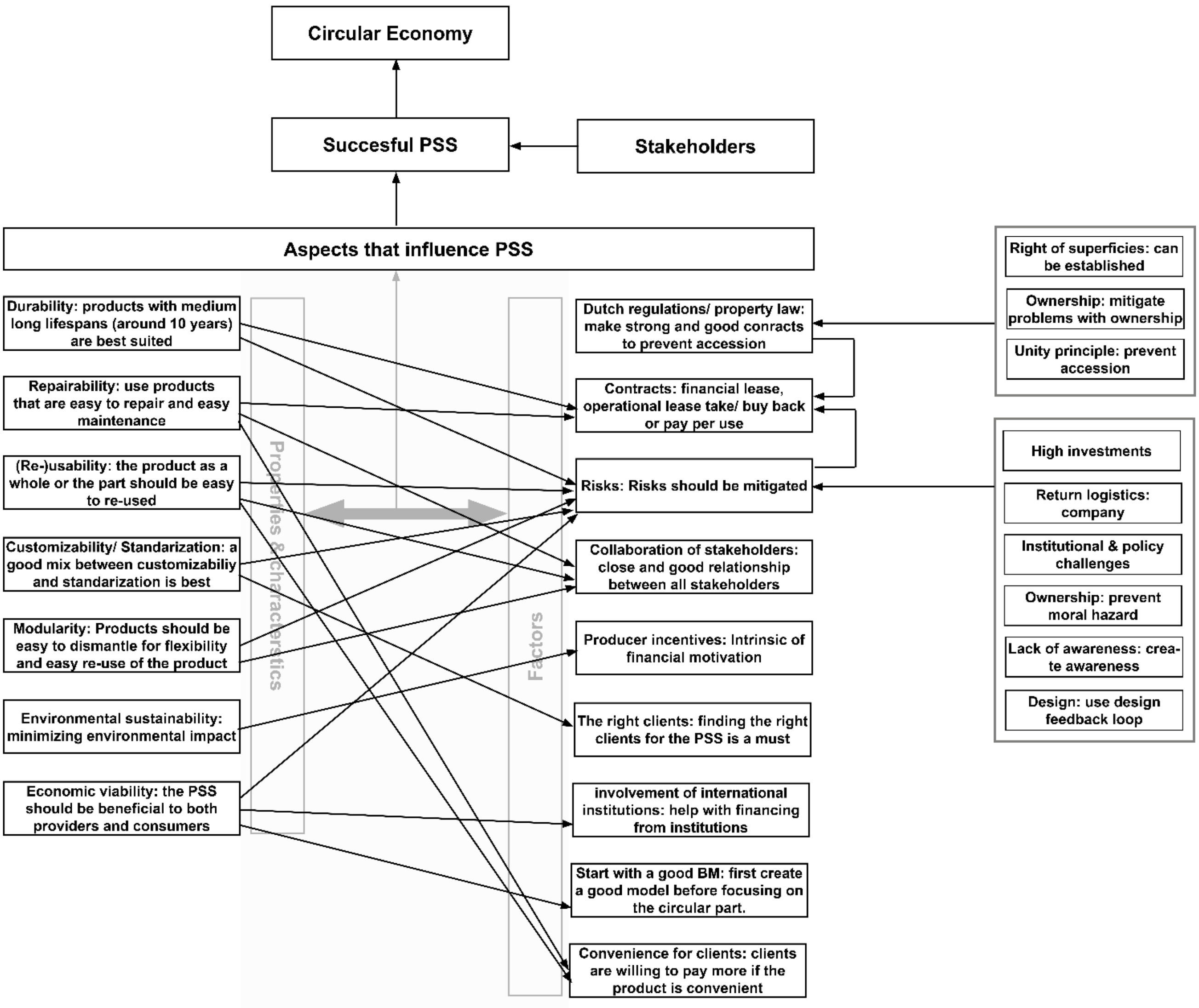

Figure 9.1 The perfect PSS (own figure)

Secondly, identifying the essential properties and characteristics of a viable PSS is crucial. These characteristics include attributes like durability, repairability, (re-)usability, customizability/ standardization, modularity, environmental sustainability, and economic viability, all of which contribute to the conception of an ideal PSS as illustrated in Figure 9.1. For PSS to be viable, product selection must align with these identified characteristics and properties. This approach will help determine which products are suitable for a PSS model.

This research has identified the suitability of various products for implementation into a PSS framework. Importantly, not all products were found to be equally suitable for PSS, with their appropriateness being dependent upon several factors. The research categorized products into three groups: 'Suitable,' 'Potential,' and 'Not Suitable,' providing a clear comparative perspective on each product's compatibility with the PSS model. For example, items such as dividing walls, bathrooms, kitchens, fencing, gutters, radiators, A/C units, escalators, staircases, drainage systems, sun protection elements, insulation materials, security systems, and smart building technologies were considered 'Suitable.' However, their integration into a PSS model might involve complexities related to customization requirements and integration with other building systems.

In contrast, bricks were deemed 'Not Suitable,' largely due to the challenges surrounding their weight and complexities in installation and disassembly. Several products, such as built-in packages, boilers, heat pumps, thermostats, and pipework, were categorized as 'Potential,' indicating that they could be integrated into a PSS model with careful planning and consideration of specific requirements. Overall, the majority of examined products hold promise for inclusion in a PSS within the Netherlands' built environment. However, their successful integration will necessitate meticulous planning and implementation, addressing legal, contractual, and logistical aspects, and aligning with the specific requirements of the Dutch built environment.

However the readiness of companies to embrace this model is also crucial. Many companies currently lack a logistical branch necessary for the transition to a PSS model. Furthermore, all stakeholders, ranging from customers to suppliers, need to be more aware of the CE. In fact, government intervention in the form of regulations could serve to make CE mandatory, further encouraging the adoption of PSS.

Legal adjustments could also facilitate the use of lease contracts for various building elements, easing the transition to PSS. It might be strategic to first focus on making PSS financially viable before emphasizing circularity, ensuring a sustainable transition. But to eventually expand PSS to its fullest potential, the emphasis must be placed on sustainability and circularity despite potential financial challenges. Contractual complexities, coupled with choices in design and materials, present obstacles that need to be tackled for the successful adoption of PSS. In addition, potential market mismatches, determined by legislation, practical realities, and consumer preferences, must be addressed.

It is crucial to conduct pilot projects for each potential product to trial and validate their suitability within the PSS model. Furthermore, the role of stakeholders is pivotal in this transformation, with effective communication and interest alignment being key. However, the hurdles to adopting PSS are not impossible, but overcoming them will require collective action. The solutions cannot be achieved by single entities, highlighting the importance of collaboration among various parties. The prospect of a society less reliant on ownership is within reach, but it will necessitate concerted efforts.

In summary, PSS presents a transformative potential for the built environment, fostering greater sustainability and resilience. Yet, realizing this potential necessitates collective efforts from all stakeholders to navigate existing barriers and fully unlock the benefits of the PSS model. By advocating for and integrating PSS, we can transition the built environment into a sector that aligns with the principles of the circular economy, thereby contributing to a sustainable and prosperous future for all.

Changes in Dutch property law for creating a better legal environment and make PSS possible:

Dutch law reform could create an enabling environment to facilitate the adoption of PSS in the built environment. The law needs to cater to the difficulties of PSS, particularly in scenarios involving unintentional transfer of ownership through accession while under a lease contract. It is advised to ensure that lease agreements are crafted to provide for adherence even in the event of unintended ownership transfers. Considering potential breaches of lease agreements, companies might opt for legal procedures for product retrieval or incorporate penalty clauses within the contract. Yet, the latter approach contradicts circular economy principles as it values monetary compensation over product reuse.

In the face of complications with accession regulations, lease agreements offer sufficient protection, ensuring the product's return to the producer. However, they should be detailed enough to address the possibility of client or provider insolvency. When bankruptcy enters the equation, manufacturers are advised to craft terms that enable product repossession under predefined conditions.

Creating restricted property rights, such as superficies rights or building lease on a product, could prevent unintended ownership transfers through accession. However, this approach is viable only for products that are sufficiently individualized, separable, and economically exploitable as independent entities.

Given the current legal uncertainties surrounding PSS in the built environment, it is evident that Dutch property law needs adjustment to better align with the principles of the circular economy. Therefore, the recommendation for lawmakers and stakeholders is to explore amendments to Dutch law, especially the civil code: Article 5:3 BW and Article 3:4 BW, that state rulings of accession and common opinion. These laws should include possibilities to effectively support and catalyse the transition to a circular economy through the implementation of PSS.

CHAPTER 10

REFERENCES

CHAPTER 10: References

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APPENDIX

APPENDIX

I. Extensive study existing PSS
II. Interview protocol
III. Informed consent form interviews
IV. Material list
V. Co-occurrence table
VI. Research Design

Appendix I Extensive study existing PSS


CASE 1 Façade as a Service (TU Delft leasing project)

The TU Delft leasing project consisted out of two field pilot prototypes: The EWI faculty building Façade Leasing technical mock-up in 2017 and the CiTG faculty building large-scale demonstrator prototype in 2019. The CiTG building explored besides the technical aspects also the broader aspects of the façade, such as the drivers and barriers related to the implementations through a PSS contract. The basis of the façade leasing model is the redistribution of activities related to design, engineering, construction, financing and end of service reprocessing of the façade and its integrated systems. These activities are distributes among all the different stakeholders involved in the project according to their capabilities (Aguerre et al., 2019).

Economic

Different challenges are tackled with the distribution of the activities. Facade system suppliers get a competitive edge and boost the value of their product-service offerings, which leads to larger profit margins and monetary stability during recessionary times. It is still important to remember the value of deriving a higher percentage of revenue from ongoing contracts such as maintenance and cleaning, rather than new projects (Aguerre et al., 2019). In global crisis of 2008 many manufactures went bankrupt, creating a steady revenue stream from ongoing contracts is of importance (Cleton, 2015).

Financial

Normally to put a new façade on your building a high investment is needed, with using the façade as a PSS monthly or yearly fees are paid. This type of model is especially convenient for institutional building owners (universities, governments, corporations), for whom the building is used to carry out their primary functions and not see the real estate as an asset. For these businesses the investments of structural component like facades will come at the expense of other investments that are more strategically relevant (Aguerre et al., 2019). It can be challenging to justify the significant cost of façade and building system renovations using conventional metrics like return on investment. These difficulties may be resolved and the cash-flow analysis of costs and benefits made easier by breaking up the costs of the façade into monthly payments. The traditional mindset may be set aside by doing away with the requirement for an initial investment, and emphasis can be placed on values other than just financial savings (Aguerre et al., 2019).

The consortium examined the supplier's cash flow during the project, where the supplier had no financing from other parties, and found that after a few jobs, the facade fabricator's balance sheet collapsed and its credit worthiness was significantly diminished. Financial institutions should step in. and relieve the façade fabricator of the burden that come with these high investment costs, by financing the façade system in advance in exchange for regular financing fee (Aguerre et al., 2019)

Technological/ Design

The Design of the façade is made through a design feedback loop, where the different stakeholders where involved for the new and existing functional requirements that needed to be in order to enable the construction of the façade, such as the construction, financing, operation, management and/or monitoring of the PSS contract, as well as the high-value maintenance and recovery of components and materials at the end of the contracting period (Aguerre et al., 2019). This PSS created a new opportunity for clients to improve the quality of their building. With the design of the façade the energetic and technical performance are of importance. Using this type of façade can lead to real estate value and rentability of the building without a very large initial investments, but monthly or yearly fees (Aguerre et al., 2019).

Legal and contracts

The thesis of Van de Vondervoort (2019) investigates the legal consequences of using facades as a PSS. He states that first it is important to know if façade panels can be gained by accession through the ground of Art. 5:20(1)(e) BW. The panels are not directly united with the ground, however they are indirectly united with the ground through a building. If façade panels qualify as 'works' within the meaning of Art 5:20(1)(e) BW, they could be drawn to the ground through the association with a building.

To date, it is seen as a social consensus that the panels are movable property but mean to stay in a building. However, the meaning of the panels in a PSS is that they are movable and not meant to stay in the building permanently, they are designed for repurposing. The public opinion play an important role regarding the purpose of the product. Therefor when the intention of the façade manufactures are known to the public, that the façade is not intended to remain permanently in a building, than the common opinion could change. As a result, a façade board cannot be regarded as immovable within the meaning of Art. 3:3(1) BW and no accession will take place.

The façade is designed as a modular façade by the TU Delft. The façade is designed in such a way that it can be easily dismantled and taken out of the building it its entirety without causing any damage to the building (Beerda, 2018), there for the second art. 3:4 BW will not cause any problems. According to Koolhoven (2018) the second art. will not cause any problems, however the criterion in the first paragraph, the concept of common opinion, is fleshed out by a number of indications, including 'constructive alignment' and 'incompleteness'.

It should be assessed whether the façade is indispensable for a building from a social point of view and whether a building can still fulfil its function in the absence of the façade. According to Van de Vondervoort (2019) it is expected that constructively a building will be considered unfinished without a façade, due to lack of insulation and safety. In case law, façade panels are considered a necessary part of a habitable building and thus form a unit (Koolhoven, 2018)

With regard to façade panels installed in buildings, current public opinions in both the general and the special mode of accession led to the conclusion that there was indeed accession. As Koolhoven (2018) and Ploeger (2019) argued, these conceptions of public opinion exist because the current linear construction economy is geared towards the unity of property. Modern society puts an emphasis on acquiring complete ownership when purchasing a property. Facades are thought to be necessary for a liveable structure. They are also said to be designed to stay in a structure forever by nature and design. While the government wants to end the linear economy, society's expectations have not (yet) been adjusted to circular principles.

Contract

For the façade leasing three primary parties are mutually bound by contractual agreements and financial commitments, as shown in figure A. For the CiTG case-study there is a contract under a façade leasing model throughout a 15-year complete lease duration followed by a service contract. The façade leasing model contrasts the conventional choice of little refurbishment with substantial maintenance postponed (i.e. delayed) until it is no longer physically feasible in 2033 with a fully new façade contracted under a "Facade Leasing" model. Only operating expenditures must be continued to be paid, under a service contract, after year 15, as long as the facade is still in place, as the principal has been fully returned (Aguerre et al., 2019). However if the lease contract will be upheld in legal proceedings still needs to be proven (Van de Vondervoort, 2019).

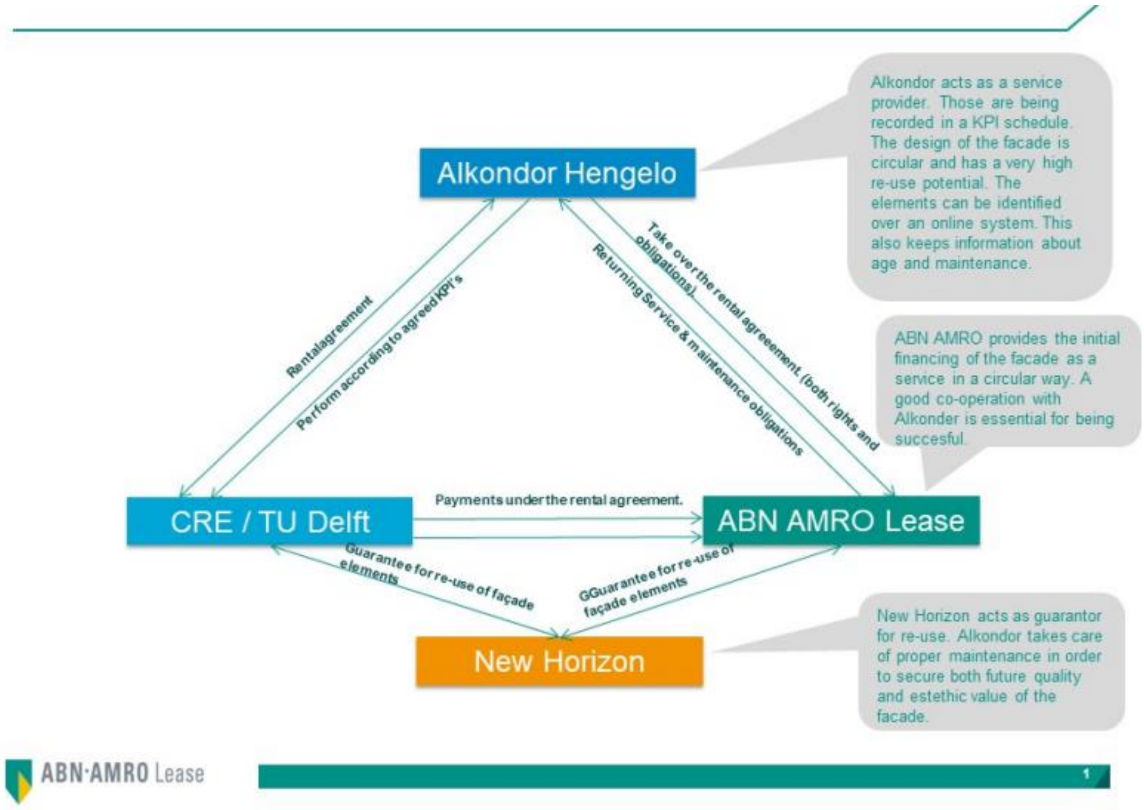

Figure A: contracting between the different parties (Aguerre et al., 2019)

TAKE AWAYS

- Design: feedback loop
- The right clients! Such as institutional building owners, where a onetime big investment is not convenient for the cashflows and multiple smaller payments is preferred.
- Involve Financial institutions and they should pay initial investments

CASE 2: Elevator as a service (Mitsubishi)

Mitsubishi is a service provider for vertical mobility: elevator as a service. They provide the total package, where the user of the product only pays for the use. One of the elevators is the sustainable elevator: Move, which uses their M-Use utility model. This elevator is built according to the cradle-to-cradle philosophy. The elevators are used in different buildings within the Netherlands, such as the residential tower 'Zalmhaven' in Rotterdam, apartment complex Dokkum Lyceum in Dokkum and multi-tenant building Park 20/20 in Amsterdam. The Park 20/20 is developed by the development partners: Delta Development Group, VolkerWessels, Reggeborgh Group and William McDonough + Partners. The Delta Development Group implemented the Mitsubishi elevator concept M-Use. Park 20/20 has two elevators of Mitsubishi within the NOW building. Zwart (2018) & KPMG (2016) did a case study on elevators and the BM of Mitsubishi within this building.

Economic

The elevator as a service is a new step in circular use. The elevators placed in Park 20/20 are developed the same way as the park, according to the cradle to cradle principles. The whole building is designed for disassembly (Mitsubishi, 2020). The elevators are monitored during the use period and therefor have longer lifespan than the regular lift, since the supplier can see when the lifts need maintenance. The supplier also has a higher incentive to deliver a high quality lift, because they still own the lift and only provide the service. The client has fixed costs and doesn't have any surprises in their rental period.

Financial

The Delta Development group reached out to Mitsubishi initially to buy elevators, however a high quality elevator was too expensive and a lower quality would lead to higher maintenance costs at the end. The conclusion was that they were not actually looking for elevators but for vertical transport. Mitsubishi transferred from the traditional model towards a PSS. In this new model the product was leased under a full service operational lease, and the ownership would remain with Mitsubishi. As a result, providers are motivated to reduce the need for maintenance, construct goods for long-term endurance, and reuse and recycle parts (Zwart, 2018).

The Delta Development group works with the principle 'not more than usual', therefor it was important the total costs of usage would not be higher when buying a new elevator (Zwart, 2018). In their case study KPMG (2016) did a true valuation, where total costs of usage and two external costs, environmental and socio-economic, were analysed with the Mitsubishi elevators for Park 20/20. According to the findings, leasing elevators makes more sense from a financial and societal value standpoint than purchasing the elevators (KPMG, 2016). This made it easier for the Delta Development group and Mitsubishi to demonstrate and describe the advantages of leasing to their stakeholders. The Mitsubishi lift operates with a better total energy efficiency and has fewer disruptions. It was chosen by Delta, Mitsubishi, and Standard Life to adopt the Mitsubishi "Elevator as a Service," now known as M-Use, in the NOW building based on the study of KPMG (2016) as well as Delta's and Mitsubishi's own research.

The funding of this new BM is the main financial obstacle now standing in the way of PSS. Mitsubishi no longer sells the items with their M-Use model. Instead, it now charges a monthly fee to those who utilise its elevators. So, there is a new requirement for finance, however the majority of funders and bankers don't want to finance this model yet. Their existing calculating techniques can scarcely estimate the risks of M-Use and the residual value the lift has. Consequently, financial possibilities are crucial to advancing the M-Use scale-up phase (Zwart, 2018).

It is important to note that the main driver behind the new BM was the intrinsic motivation of the CEO of Delta Development. He sought to demonstrate that this novel paradigm, which encourages circularity, could really be effective on many levels and for a wide range of stakeholders.

Technological/ design

The elevator is demountable and comes with a material passport in Madaster, so the elevator's circularity may be proven (Mitsubishi, n.d.). This online materials passport, where all materials are mapped and provides access to the life cycles of all components of the elevator. Furthermore, Mitsubishi can monitor (from a distance) utilisation statistics by integrating sensors and clever software into the lift. Mitsubishi is aware of how many trips a lift made, for how long, and what impact those trips had on key lift parts. Mitsubishi can match their maintenance schedule with the elevator's actual usage by tracking utilisation in real time and comparing it to historical data (Mitsubishi, 2021). This guarantees that each lift receives the appropriate maintenance at the appropriate time, ensuring efficient material usage and a long lifespan. The maintenance schedule results in an increased lifespan when compared to a conventional lift. Second, Mitsubishi has a take-back programme in which the elevators are disassembled and parts are reused whenever feasible (Zwart, 2018). Some parts are recycled and utilised once again. The elevator's design is always being improved in order to increase circularity. Also, the elevator is made to be readily disassembled, including in accordance with the "non-welding, non-glue" idea (Mitsubishi, 2021). This makes it considerably simpler to reuse materials and components. However, it is important to mention that takeback has not yet happened because the elevator has only been in place since 2015 with a 20-year term (Zwart, 2018).

Legal/ contract

The elevators are linked to the NOW building that is owned by a third party, and as mentioned earlier in paragraph XX this can cause problems with Dutch law regarding ownership rights. However to prevent accession to happen, Mitsubishi established a building right for the elevators for the building. This right stipulates that, in the event of bankruptcy, Mitsubishi will continue to be the owner of the elevators that are tied to a product, building (Zwart, 2018). According to a building right, Mitsubishi is and will always be the owner of the elevators. In the event that Mitsubishi defaults, the building owner may purchase the lift.

The contract used for the elevators in the NOW building are operational lease contracts for 20 years, based on performance, because of the building right established the ownership of the elevators lies with Mitsubishi. The contract includes all the maintenance, repairs, replacements and tests. The original parties to the contract were Delta and Mitsubishi. As the building was finished, Standard Life took over the contract from Delta. The building was sold by Delta to Standard Life, hence the ownership of the building itself was moved, necessitating the transferability of the contract as well. At the end of the contracting period the owner of the building has two options: extending the contract, for a lower monthly fee or buy the lift from Mitsubishi for the residual value.

Take aways:

- Madaster
- No welding and gluing → easier for to dismantling of products.

- Housing associations and associations of owners who don’t cannot afford big investments, but rather pay small amounts over multiple years can be good customers
- Intrinsic motivation of stakeholders!
- Bankers don’t want to finance the new BM, because their current calculation methods can hardly evaluate the products.

Case 3: Bikes as a service (Swapfiets)

Swapfiets launched in the Netherlands in 2014 with their first bikes in Delft. Swapfiets is a service provider for bikes who uses a bicycle lease system on subscription basis for its customers. Subscription represents a use-oriented PSS (Tukker, 2004). The customer can registrate online via APP or website to get their own bike, which will be brought to location of the customer within 1 day, the maintenance of the bike is also included in the service, which they will do at a by the customer chosen place within 48 hours (Swapfiets, n.d.).

Many researchers have studied mobility as a service and especially the newer brand Swapfiets with their bike leasing system. Niessen et al. (2022) describes the impact of business sufficiency with bicycle subscription with Swapfiets as their case study. Also Ma et al. (2020) does a case study on bicycle sharing in the Netherlands where they explain the impact of Swapfiets and other cases.

Economic

According to research leasing can reduce product waste and increase product reusability. Researchers state that durable goods and a systems for repair and remanufacture are needed for it to be sustainable. However, in practise, customers may be less cautious with subscription bicycles compared to used or newly purchased ones. Tukker (2015) hypothesises that consumers may be more cautious with access-based products due to concerns about adverse consequences from wear and tear.

Strategies for sufficiency include awareness-raising and design, for durability and reparability. Through the 2021 "Consume less, Enjoy more" campaign, for example, Swapfiets wants to improve the quality of life in cities by making them cleaner, greener, and more liveable (Swapfiets, 2021). However Swapfiets does not have a mechanism in place to change the bicycles' supply chain. The current manner they operate is not long-term oriented (Niessen et al., 2022). A change in the material flow of Swapfiets is necessary. The present flow is not sustainable and could seriously damage Swapfiets' brand reputation. Also, it is economically unwise since disposing of the frames results in direct expenditures equal to their lost worth. Closing the loop of materials can boost the Swapfiets' brand and economic value (Niessen et al., 2022). Also a closed material loop is a common element of the success of a PSS (Niessen et al., 2022). A sustainable product service system has a closed material loop. One of the primary motivations for developing a sustainable PSS is to optimise the lifespan to produce an economic advantage.

Financial

Fietsersbond (2021) calculated if leasing a bike through Swapfiets is cheaper than owning your own bike. For a bike from Swapfiets you pay a regular amount per month. In two years you will have approximately the same amount of money for a new similar bike. Swapfiets also charges the client when the bikes get stolen (with a smaller amount than a new bike). Swapfiets is clearly not the best option if you plan to use your bike for a longer period than 2 years. The cheapest bike option would be to buy a second hand bike and do some maintenance yourself, however not everybody has the time or inclination to do so. This explains Swapfiets's popularity, since they are not the cheapest option. If a chain breaks, you won't get muddy since a small Swapfiets automobile will save the day. Additionally, the client must pay if your bike is stolen, but your next Swapfiets will be delivered right to your house. The client not required to look for a different bike on your own. The client is relieved of the inconvenience. In the research of Niessen et al. (2022) convenience and the ease of subscription is also mentioned as one of the recurring themes customers choose for Swapfiets. In the study of Ma et al. (2020) users of Swapfiets also indicated that they choose for Swapfiets, because they have to be less worried about the bike being stolen or damaged and also the good quality of the bikes were a motivation users choose for Swapfiets.

Technological/ design

Swapfiets choose their prominent blue front tire as a marketing strategy (Swapfiets, 2021). The bikes are identified all through the city. The design of the bike is a work in progress, first there was chosen for a closed chain case, however this took to much time in the workshop and there was chosen for half open/ closed chain case. This is less labour-intensive and a much cheaper option. It also turned out that traditional steel rims often break down, so they were replaced with the sturdier double-walled aluminium rims. The first bikes had lights that needed batteries. These have been replaced by Danish Reelights, this is a system that revolves around magnets, which eliminates the need to change the batteries. None of the bikes have a rear rack, this is done on purpose to prevent people from jumping on the back and therefor ruining the rear wheel leading to more repairs. To still be able to carry things, every bike has a small front rack. To be able to find your bike, Swapfiets provides customisation elements such as coloured frame and bell or stickers. These were considered as useful by the customers (Niessen et al., 2022).

Legal/contracts

Lease contract, with monthly payments which can be terminated monthly. The ownership of the bike is with Swapfiets and they also handle all the maintenance and replacements of the bike when the bike stolen for a small payment. The bike is not shared, but only the customer can use the bike. Swapfiets (2021) stated that their biggest problem is customers forgetting where they left their bike and theft. Filing reports about the theft is pointless, since the police does not do anything with the theft and stolen bikes are not their priority. From all the missing bikes 40-50 percent is lost, however Swapfiets cannot take these bikes back if this bike is reported as stolen by the police until approval from the public prosecutor. This process costs a lot time and money. According to Swapfiets (2022) a track and trace system could be a solution, however privacy regulations would be an issue.

Take aways

- Convenience and comfort of the product as a service!!
- Design for misconduct
- Design for easy maintenance
- Design process is an ongoing process
- A good BM can already start and later on look a the circularity, but the foundation of a good BM can create a good PSS.

Appendix II: interview protocol (in Dutch)

Interview: Britt Belt
Delft University of Technology – Faculty of Architecture | Management in the built environment
Student number: 4663691
Interviewee: XX
Duration: 30-60 min

Eng

Interview for master thesis from Britt Belt for TU Delft. The thesis is a research into how product service systems can be applied in the Built Environment and how this can contribute to a more circular environment. Different possibilities for various components are investigated. Different companies that are involved in the supply chain of products are involved in the interviews. What are the motivations and drivers behind certain choices and when producing/ demolishing/ buying the product is the repurposing of the product taken into consideration.

Main research question of the research: How can product service systems be applied in the Built Environment and expended as much as possible?

NL

Interview voor masterscriptie van Britt Belt voor TU Delft. De scriptie is een onderzoek naar hoe product service systemen kunnen worden toegepast in de Built Environment en hoe dit kan bijdragen aan een meer circulaire omgeving. Verschillende mogelijkheden voor verschillende onderdelen worden onderzocht. Verschillende bedrijven die betrokken zijn bij de supply chain van producten zijn betrokken bij de interviews. Wat zijn de motivaties en drijfveren achter bepaalde keuzes en wordt er bij de productie/sloop/koop rekening gehouden met hergebruik van het product.

Hoofdvraag van het onderzoek: Hoe kunnen productservicesystemen worden toegepast in de Gebouwde Omgeving en zoveel mogelijk worden geëxploiteerd?

Start:

24h van te voren: sending teams–link

30 min. For start: testing equipment

Recording via Microsoft Teams + Audio recording via phone

Start Interview

Goedemorgen/Middag fijn dat u de tijd heeft om aan ons onderzoek mee te werken. Ik zal mij eerst even voorstellen …

Vind je het goed als ik dit interview opneem? [informed consent]

Bezig met mijn afstudeer onderzoek voor de TU Delft van de master track Management in the built Environment (MBE). + uitleggen van onderzoek en hoe het onderzoek in elkaar zit en welke fase er nu bezig is. (uitleg PSS & circulariteit)

Deel 1: Introductie Interviewee

- Kun je iets over je achtergrond vertellen?
- Waar werk je en wat doet het bedrijf?
- Wat is uw huidige rol binnen uw bedrijf?

- Als we kijken naar de gehele supply chain van gebouwonderdelen/producten, waar positioneert u zich in deze supply chain van een product/gebouwonderdeel?
- Wat zijn de belangrijkste drijfveren achter de keuzes die worden gemaakt? (Verduidelijk welke keuzes hiermee bedoeld worden)

Deel 2: Producten als een service (zo open mogelijk)

(Betekenis PSS moet duidelijk zijn)

- Heeft uw bedrijf ooit overwogen om producten als een service aan te bieden?
    - Zo ja, waarom wel/niet?
    - Ga verder in op de mogelijkheden hiervan.
- Slopers: Verkoopt uw bedrijf producten die uit gebouwen worden verwijderd? Waarom en hoe werkt dat precies? Zou het niet makkelijker zijn om ze aan te bieden met een terugkoop-/terugnamesysteem?
- Leveranciers: Zou het voordeliger zijn om producten als een service aan te bieden?
    - Denk aan cashflow: zekerheid van inkomsten tijdens crisistijden, enz.
- Beleggers: Wat is de grootste drijfveer om bepaalde keuzes te maken? (Maak het concreter: financieel, risico's, enz.)
    - Introduceer het goed en stel open vragen.
- Hoe ziet u een samenleving voor zich die bestaat uit verschillende servicesystemen?
- Zou het mogelijk zijn om een gebouw casco op te leveren en alles te leasen? Waarom wel/niet?
- Hoe belangrijk is circulariteit voor u?
    - Vindt u dit belangrijk? Waarom wel/niet?
    - Speelt dit een rol bij het nemen van beslissingen?
- Welke problemen worden ervaren bij circulaire bouwprojecten? (Met betrekking tot contracten)

Deel 3: bespreken gevonden factoren (meer gesloten + resultaten voorleggen)

- Waar moet volgens jou een product aan voldoen om geschikt te zijn?
- Naar factoren vragen en gevonden factoren bespreken:
    - Nederlandse wet- en regelgeving
    - Contract mogelijkheden
    - Doorloop tijd
    - Risico’s
    - Redenen en stimulaties om PSS te beginnen.
    - Samenwerkingen met stakeholders
- Eigenschappen & kenmerken van producten bespreken
- Voorzie je problemen?
- Wat moet er voor jou gebeuren om dit model toe te passen?
- Welke factoren/ eigen schappen zijn van belang volgens jou?

Deel 4: Vragen naar gevonden mogelijkheden

Afhankelijk van interviewee, een open discussie over de gevonden producten

Slot interview

- Als formulier nog niet ondertekend is → Zou je nog het consent formulier ondertekenen?
- Bedanken voor deelname aan dit interview en tijd. Fijne dag etc.

Checklist na afloop interview:

- Herrineringsmail informed consent
- Transcriberen van interview
- Coderen in Atlas Ti.

Appendix III: Informed consent form interviews (in Dutch)

Rotterdam, 06 april 2023.

Betreft: Geïnformeerde toestemming deelname onderzoek producten als een service in de gebouwde omgeving

Geachte heer/mevrouw,

De wereld verandert snel en klimaatverandering en schaarste van natuurlijke hulpbronnen worden steeds grotere problemen. Het is van essentieel belang om op zoek te gaan naar nieuwe oplossingen, zoals het creëren van een circulaire economie, om ervoor te zorgen dat de aarde duurzaam blijft voor de lange termijn. In de gebouwde omgeving is deze verandering ook merkbaar. Er is een beperkte voorraad aan natuurlijke hulpbronnen en als schaarste toeneemt, zullen de prijzen stijgen. Om circulariteit mogelijk te maken, is het essentieel om hergebruik mogelijk te maken en de verschillende stakeholders berokken verantwoordelijkheid nemen.

Een voorbeeld van een model om een circulaire economie in de gebouwde omgeving te creëren, is het gebruik van product service systemen. De klant betaalt hier voor het gebruik van een dienst of product in plaats van eigendom. Hierdoor worden producenten gestimuleerd om producten te maken die langer meegaan en van betere kwaliteit zijn, terwijl klanten betalen voor toegang tot het product. Om product-service systemen in de gebouwde omgeving te implementeren, zijn er significante veranderingen nodig in de herontwikkeling van gebouwen en effectieve samenwerking tussen belanghebbenden. Echter, onderzoek toont aan dat dit proces moeilijk is en een gevoelige samenwerking vereist onder alle belanghebbenden. Conflicterende financiële prikkels en commerciële belangen spelen een grote rol en verhogen complexiteit van het gebruik van een product service systeem.

Omdat de lineaire economie niet eeuwig houdbaar is onderzoek ik product service systemen in de gebouwde omgeving als een oplossing om een circulaire economie te creëren. Het doel is om te onderzoeken hoe producten als een service in de gebouwde omgeving zoveel mogelijk gebruikt kunnen worden. In dit onderzoek wordt gekeken hoe breed het model tot nu toe is toegepast en wat alle nieuwe mogelijkheden zijn, samen met de kenmerken en eigenschappen die nodig zijn om een succesvol product service systeem te creëren.

Deze studie wordt uitgevoerd door een student aan de TU Delft voor een afstudeerscriptie voor de MSc Architecture, Urbanism and Building Sciences aan de Bouwkunde faculteit in delft. Het interview wordt uitgevoerd door de student Britt Belt. Het interview duurt ca. 30 tot 60 minuten. Graag zou ik het interview op willen nemen om het achteraf uit te kunnen werken. Het doel van het interview is om te leren van uw ervaringen en de mogelijkheden omtrent product service systemen in de gebouwde omgeving te bespreken.

Vanuit de universiteit zijn we gewend om nog eens apart te vragen of u mee wilt doen aan het onderzoek en of u het goed vindt om dit interview op te nemen. U mag ook nu zeggen dat u liever niet mee doet. U kunt u ook later nog bedenken en uw deelname intrekken zonder opgave van reden. U mag iedere vraag die wij stellen weigeren te beantwoorden.

Als u mee doet, dan vragen we u om uw handtekening onderaan deze brief te zetten en een pdf aan ons te retourneren. Wij zetten dan ook onze handtekening. Dat doen we zodat u zeker weet dat we vertrouwelijk omgaan met uw gegevens en antwoorden. Ook krijgt uw organisatie het interviewverslag niet te zien of te horen. Wij maken een algemeen en anoniem verslag over de ervaringen van verschillende deelnemers van verschillende organisaties. Als ik uw woorden aanhalen, dan beloven ik om uw naam niet gebruiken en zorgen we dat het niet duidelijk is wie dit gezegd kan hebben. Ik zal uw naam- en contactgegevens meteen na afloop van het onderzoek vernietigen.

Als u vragen heeft over dit onderzoek, kunt u contact met ons opnemen: Britt Belt, b.a.belt@student.tudelft.nl, +31 6 22 54 64 61.

Als u mee wilt doen aan dit interview, wilt u dan de onderstaande verklaring invullen en ondertekenen?

Met vriendelijke groet,

Britt Belt

In te vullen door de medewerker & studenten

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en belasting van het onderzoek.

Mijn vragen zijn naar tevredenheid beantwoord.

Ik begrijp dat het geluids- en/of beeldmateriaal (of de bewerking daarvan) en de overige verzamelde gegevens uitsluitend voor analyse en wetenschappelijke presentatie en publicaties zal worden gebruikt.

Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Ik heb dit formulier gelezen of het formulier is mij voorgelezen en ik stem in met deelname aan het onderzoek.

- ☐ **Graag ontvang ik aan het eind van het onderzoek een korte samenvatting van de resultaten van het onderzoek. Om deze reden verleen ik toestemming om mijn naam- en adresgegevens tot het eind van het onderzoek te bewaren.**

Plaats:

Datum:

_ _
(Volledige naam, in blokletters)

_ _
(Handtekening deelnemer)

‘Ik heb toelichting gegeven op het onderzoek. Ik verklaar dat ik bereid nog opkomende vragen over het onderzoek naar vermogen te beantwoorden.’

Britt Belt

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Appendix IV: Material list of products

1. **Windows/ doors/ frames:** These are essential components of buildings that provide access, ventilation, and natural light. They can be made of various materials, including wood, metal, and PVC (polyvinyl chloride). The choice of material often depends on factors such as cost, durability, and aesthetic preferences
2. **Flooring:** Flooring forms the walking surface in any building or structure. It can be made of various materials, including hardwood, bamboo, laminate, vinyl, ceramic tiles, and carpet, each having its unique characteristics, advantages, and disadvantages
3. **Dividing walls:** These are non-load-bearing walls that separate spaces within a building. They can be made of a variety of materials, including plasterboard, timber, brick, glass, and metal
4. **Bathrooms:** Bathrooms are rooms in a building that contain a toilet and usually a sink and either a bathtub or a shower. The materials used in bathrooms need to withstand moisture and frequent cleaning. They typically include ceramics, glass, stainless steel, and sometimes wood for cabinetry
5. **Fencing:** Fencing serves several purposes, such as providing privacy, security, or decoration. Fencing can be made from materials such as wood, vinyl, aluminium, steel, and chain link
6. **Bricks:** Bricks are rectangular blocks typically made of fired or sun-dried clay, used in building. They are known for their durability, strength, and insulation properties
7. **(Roof) tiles:** Roof tiles are designed mainly to keep out rain, and are traditionally made from locally available materials such as terracotta or slate. Modern materials such as concrete and plastic are also used and some clay tiles have a waterproof glaze
8. **(Roof) corrugated plates:** These are used as roofing material and are often made from galvanized steel or aluminium. They are known for their strength, durability, and resistance to extreme weather conditions
9. **Gutters:** Gutters are essential for directing rainwater away from a building to prevent water damage. They are typically made from materials such as vinyl, aluminium, steel, or copper
10. **Radiators/ AC:** Radiators distribute heat, typically through convection, to heat space in buildings. Air conditioners (AC) are used to cool and dehumidify indoor air. They can be made from a variety of materials, including aluminium
11. Escalator: An escalator is a moving staircase that carries people between floors of a building. They are typically made of stainless steel and include steps, handrails, and balustrades
12. Staircases: Staircases provide vertical circulation between the floors of a building. They can be made from various materials, including wood, concrete, stone, and metal
13. Drainage: Drainage systems are crucial for removing water from buildings. They are typically made from materials such as PVC, cast iron, and copper
14. Furniture: Furniture refers to movable objects intended to support various human activities such as seating, eating, and sleeping. They can be made from a variety of materials, including wood, metal, plastics, and textiles

15. Built-in package: This usually refers to fixtures or appliances that are installed or fixed permanently in a building. Examples can include kitchen appliances or built-in wardrobes. The materials used will vary significantly depending on the specific item

16. Boiler: A boiler is a closed vessel in which water or other fluid is heated. The fluid does not necessarily boil. They are typically made from steel or cast iron

17. Heat pump: A heat pump is a device that transfers heat energy from a source of heat to a destination called a "heat sink". They can be composed of various materials, including copper for the coils, aluminium for the fins, and steel for the compressor and motor

18. Thermostat: A thermostat is a device that regulates the temperature of a system so that the system's temperature is maintained near a desired setpoint. They are usually made from plastic and metal

19. Pipework: Pipework carries fluids (liquids and gases) from one location to another. They can be made from a variety of materials, including copper, steel, and PVC

20. Sun protection (in & out): Sun protection systems such as blinds, curtains, shutters, and awnings are used to control heat and light from the sun. Outdoor sun protection can include pergolas, canopies, and sunshades. These can be made from various materials such as fabric, wood, aluminium, and plastic

21. Insulation material: Insulation materials are used to slow down the rate of heat transfer. They can be made from various materials such as fiberglass, cellulose, mineral wool, and foam board. Insulation is essential for maintaining comfortable temperatures inside buildings and reducing energy consumption

22. Security systems: Security systems are used to detect intrusion or unauthorized entry into a building or area. They include components such as alarms, cameras, locks, and access control systems. These systems can be made from a variety of materials, including plastic and metal, and often incorporate electronic components

23. Smart building technologies: Smart building technologies integrate various systems and processes of a building to improve the building's performance. These technologies can include automated systems for lighting, heating, ventilation and air conditioning (HVAC), security, and other functions. They typically involve a variety of electronic and digital materials and components

24. Kitchens: Kitchens are rooms or areas where food is prepared and cooked. A typical kitchen includes components such as cabinets, countertops, and appliances (stoves, refrigerators, etc.). These can be made from a variety of materials, including wood, metal, stone, and plastic

Appendix V: Co-occurrence table

Appendix VI: Research Design