The background of the entire page is an aerial photograph of a large-scale construction site. The image shows extensive earthworks, including deep excavations, embankments, and a network of roads and channels. There are several large, circular structures, possibly water tanks or reservoirs, and various pieces of construction equipment and materials scattered across the site. The terrain is a mix of brown earth, grey concrete, and some green vegetation.

Product-service system business models in the building sector: barriers and solutions for companies

MSc. Thesis
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Product-service system business models in the building sector: barriers and solutions for companies

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Cover page image: Escondida copper mine (Wit et al., 2018)

Executive summary

Introduction

The construction sector globally exhibits a substantial consumption of raw materials and generates significant amounts of waste. It is widely recognized that the dominant linear economy approach in construction, characterized by a take-make-dispose model, is highly unsustainable. There is a growing consensus that transitioning from a linear economy to a circular economy (CE) is essential for addressing these challenges. CE focuses on prolonging the lifespan of products and their components and implementing smarter manufacturing and product use practices. By embracing the principles of CE, such as resource optimization and efficiency, the construction sector can significantly enhance its sustainability. It is imperative to consider the lifespan of buildings and adopt a Product-Service System (PSS) approach to achieve long-term sustainability objectives. PSS is a Business Model (BM) that prioritizes service provision over product sales. It encompasses concepts such as functional economy, eco-efficient service, dematerialization, and servitization. PSS is recognized as a viable solution for decoupling economic growth from resource consumption and realizing the goals of a CE. PSS has the potential to both enable and drive sustainability and CE efforts. It can enhance resource efficiency, reduce waste, and contribute significantly to achieving CE and sustainability objectives.

Problem Statement

Companies encounter barriers when adopting PSS, particularly in the building sector. The knowledge about PSS is also limited and fragmented compared to linear BMs, particularly regarding the barriers and potential solutions.

Research Objective

This study aims to understand the state-of-the-art in PSS, assess its barriers, and propose potential solutions. It focuses on the perspective of contractor companies in the building sector and formulates the following main research question.

Research Question

How can contractor companies overcome the barriers to Product-service system business models in the building sector?

The following sub-questions were formulated to address the main research question.

1. What is the state of the art of PSS in the building sector based on scientific literature?
2. What is the current state of PSS adoption by companies in the building sector in practice?
3. What are the barriers to PSS?
4. What are potential solutions to the identified barriers of PSS?

Methodology

This study applied a qualitative research method utilizing data from a literature review and semi-structured interviews to address the research question. It used the Preferred Reporting Items of Systematic reviews and Meta-Analysis (PRISMA) approach to conduct the literature review. The Scopus database and the Google Scholar Web search engine were searched using a standard procedure to identify, select, and appraise studies included in the study. The review considered studies focused on the current state of PSS, its barriers, and solutions. The

comprehensive literature search identified 774 studies. Applying the screening process resulted in 45 studies being included in the final review. Furthermore, semi-structured interviews were conducted with professionals in the building construction sector to collect data for supporting literature review findings. All the interviews were conducted online and in English, and the same questions were used.

Findings

What is the state-of-the-art of PSS in the building sector based on scientific literature?

PSS has evolved into a strategy for differentiation and improved customer loyalty, addressing needs more effectively than product-oriented solutions. The definitions of PSS identified in this study focus on meeting these needs, prioritizing environmental impact. The two of them also mention involving a network of actors and supporting infrastructure, and one of them emphasizes social aspects and partnerships. Different categories of PSS were identified, with some highlighting options available to companies from pure product sales to service delivery and others focusing on transitioning.

PSS can enable and drive sustainability and circular economy by facilitating economic growth while reducing resource consumption and promoting waste reduction. Different types of PSS have varying sustainability potential, with result-oriented PSS showing the highest potential. PSS is well-suited for high-cost, technologically advanced products with infrequent usage and minimal influence from branding or fashion. Internal benefits for companies are mainly economic, while environmental benefits favor providers and society. However, social benefits are often overlooked in PSS research.

The practical application of PSS in the building sector is limited due to the need for significant changes in internal corporate technology and supply chain management. Companies transitioning to PSS face challenges such as a lack of financial support, organizational restructuring, establishing new customer relationships, developing new contracts, and adopting new economic models. Additionally, there are insufficient policies or regulations to support PSS in the building sector. Nonetheless, sustainability, circularity, and CO₂ reduction can drive the adoption and implementation of PSS.

What is the current state of PSS adoption by companies in the building sector in practice?

Companies in the building sector offer PSS in the four layers of a building: stuff, space plan, services, and skin. The offerings include facade systems, partitions, glass walls, ceiling systems, meeting spaces, doors, windows, interior design, and even experimental concepts like living-as-a-service. However, these services primarily target business-to-business (B2B) relationships and clients such as social housing and institutional investors. The companies prioritize maintenance and buy-back guarantees, aiming to establish performance-based PSS. Initially, companies focus on the B2B market to develop knowledge and expertise before entering the more complex business-to-customer (B2C) market. They are interested in products with shorter lifespans, residual value, standardized design, and measurable performance.

What are the barriers to PSS?

The study identified 41 barriers in the literature review and 20 from interviews. Among the barriers recognized from interviews, six new barriers were identified. Lack of knowledge and understanding was the most cited barrier in the literature, while high upfront costs and low

upfront profits topped the interview responses. Financial, organizational, resources, and knowledge were the most cited barrier categories in the literature, whereas financial, resources, and supply chain were the most mentioned categories in interviews. The barriers were classified as internal, external, and mixed, with the study providing solutions for internal and mixed barriers.

What are potential solutions to the identified barriers of PSS?

Nine potential solutions were identified from literature and interviews to help companies in the building sector overcome barriers to PSS adoption. These solutions include effective leaders, separated business units, training existing personnel, hiring additional personnel, long-term relationships, horizontal integration, vertical integration, knowledge and experience transfer from other sectors, and learning by doing. Vertical integration is the most effective solution, addressing 16 barriers, followed by hiring additional personnel, separating business units, and effective leaders, which mitigate 14 barriers. Training existing personnel and fostering long-term relationships overcome 12 barriers while learning by doing addresses 6 out of 31 barriers.

How can contractor companies overcome the barriers to Product-service system business models in the building sector?

This study proposes nine solutions for overcoming barriers to PSS adoption in the building sector, as listed below:

1. Top-level management leaders who understand servitization can facilitate the transition.
2. Companies can have separate divisions to manage corporate risk and onboard personnel with the necessary competence.
3. Training existing personnel is essential for developing competences in PSS, as it differs from traditional offerings.
4. Hiring additional personnel, such as people for contract management, is necessary for acquiring new capabilities and expertise.
5. Cultivate long-term relationships with customers and other actors in the supply chain.
6. Horizontal integration aligns business strategies with companies at the same supply or value chain level to combine expertise and foster collaboration.
7. Vertical integration aligns business strategies with companies in the supply chain, offering benefits such as increased control, cost savings, operational efficiencies, and innovation.
8. Companies can leverage the knowledge and experience of other sectors.
9. Companies can gain experience and improve through small-scale experimentation, adaptation, and learning-by-doing, as predicting every outcome is impossible.

The table below enables efficient resource allocation and prioritization of solutions by recognizing that solutions' effectiveness varies across barrier categories. Additionally, the solutions are interconnected and mutually supportive.

i: Table 1: A matrix diagram showing which recommended solution is an enabler for which barrier.

| # | Categories | Barriers | Solutions | | | | | | | | |
|---|----------------|---|-------------------|--------------------------|-------------------------|--------------------------|-------------------------|------------------------|----------------------|--|-----------------------|
| | | | Effective leaders | Separated business units | Train existing personal | Hire additional personal | long-term relationships | Horizontal integration | Vertical integration | Use expertise of manufacturing companies | Use learning-by-doing |
| 1 | Customers | Long-term relationship/contracts | | X | X | X | | | | X | X |
| | | Lack of consumers interest | | | | | X | | | X | |
| | | Not able to communicate one-on-one with clients | | X | | X | | | | | |
| 2 | Supply chain | Lack of standardization | | | | | X | | X | X | |
| | | Lack of partners | X | | | | X | X | X | | |
| | | Lack of information exchange between supply chain actors | | | | | X | | X | | |
| | | Lack of long-term perspective by suppliers | X | | | | X | | X | | |
| | | Lack of trust and collaboration in the supply chain | X | | | | X | | X | | |
| | | Stakeholders resistance | X | | | | X | X | X | | |
| | | Storing of product to reuse | | | | | X | | X | | |
| 3 | Organizational | Organizational complexity or administrative burden & responsibility | X | X | X | X | | | | | |
| | | Conflicts between business functions | X | X | | | | | | | |
| | | Change in organization processes and mindset | X | X | X | X | | | | | X |
| | | Reverse logistics | X | X | X | X | X | X | X | X | X |
| | | Lack of organizational commitment | X | | | | | | | | |
| | | Lack of business strategy | X | | | | | | | | |
| | | The BM cannot be easily replicated in other areas | X | | X | X | | | | X | |
| 4 | Resources | Lack of abilities and competencies | X | X | X | X | | X | X | | X |
| | | Lack of human resource | | X | | X | | X | X | | |
| | | Lack of financial resources | | X | | | | | X | | |
| | | Proportionality, companies size, and capability | | X | X | X | X | X | X | | |
| | | Lack of information/data | | | | | X | X | X | X | X |
| 5 | Knowledge | Lack of knowledge and understanding | X | | X | X | | | | X | X |
| | | Inability to quantify economic and environmental savings of PSS | | | X | X | | | | | |
| | | Inability to deliver high-quality products | | | X | X | | | | X | |
| | | Lack of sustainability awareness | X | | X | X | | | | | |
| 6 | Financial | Profitability of existing business models | | X | | | | | | | |
| | | Financial risk due to the long service life of buildings | | X | | | | | X | | |
| | | Profit calculation | | | X | X | | | | | |
| | | R&D investment in system and service integration | | | | | X | | X | | |
| | | High upfront costs and lower upfront profits | | | | | | | X | | |

Discussion

PSS definitions in the literature focus on meeting customer need through tangible products and intangible services, and few focus on crucial elements such as the actor's network, supporting infrastructure, and collaboration. However, companies offering PSS in the building sector must consider these elements for successful adoption. Various classifications are available where Tukker's (2004) classification is widely referenced and built upon. Sustainability potential varies among different types of PSS, with result-oriented PSS having the highest potential. Providers should incorporate sustainability factors and circularity concepts to achieve sustainable and circular outcomes. PSS implementation is in the experimental phase as companies want to understand market dynamics, customer preferences, and operational requirements to refine offerings and transition to performance-based PSS. The significance of barriers in PSS research is context-dependent and understood through analyzing cited studies.

Recommendation for Practice

This study offers guidance to companies implementing PSS in the building sector. By assessing relevant barriers and utilizing recommended solutions, companies in the building sector can overcome challenges and increase the likelihood of successful PSS adopting. The matrix diagram categorizes barriers and maps potential solutions, enabling efficient resource allocation and addressing specific challenges. Circular and sustainable aspects of PSS can help overcome financial barriers, attract investors, and justify the transition.

Recommendations for Further Research

Future research can explore the customers' perspective on PSS in the building sector, exploring their perceptions, attitude, and behaviors toward adoption. In addition, further studies can specifically focus on each identified category of barriers, conducting in-depth research on their types and potential solutions. Case studies and empirical data can be employed to examine and validate the barriers and solutions identified in this study. Moreover, future research can concentrate on specific building systems or products, such as internal partition wall systems for residential and non-residential buildings, to investigate potential barriers and solutions.

Limitations

The literature search was limited to English publications, potentially causing language bias and excluding necessary non-English studies. The study used specific keywords and excluded studies that didn't mention them in the title, abstract, or keywords section, even if they discussed related concepts. The sample size for interviews was small, comprising only eight participants, and biased towards companies emphasizing CO2 reduction, circular practices, and product plus service BMs on their websites. Furthermore, this study focused on internal and mixed categories but lacked verification through a focus group, limiting its generalizability. The findings offer valuable insights for practice and future research in similar contexts.

Report Structure

Chapter 1 introduces the thesis and presents the scope, objectives, and research question. Chapter 2 explains the research methods and data collection techniques. Chapter 3 examines the state-of-the-art of PSS in the building. Chapter 4 identifies barriers to PSS in the building sector from literature and interviews. Chapter 5 analyzes drivers and potential solutions to these barriers using literature and interviews. Chapter 6 discusses the study's findings, implications, and limitations. Finally, Chapter 7 summarizes conclusions and recommendations for practice and further research.

Keywords: Product-service system, Barriers, Enablers, Business model, Sustainability, Circular economy.

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Abbreviations

| | |
|----------------|------------------------------------|
| B2B | Business-to-Business |
| B2C | Business-to-Customers |
| BM | Business model |
| C&D | Construction and Demolishing |
| CBM | Circular Business Model |
| CE | Circular Economy |
| PSS | Product-service system |
| SPSS | Sustainable Product-service system |

This chapter serves as the foundation of this study, introducing its essential components and structure. The opening section labeled 1.1 presents an overview of the topic, section 1.2 clearly defines the research problem, and section 1.3 identifies gaps in the existing literature that this study aims to address. Section 1.4 outlines the research objectives, and section 1.5 establishes the scope of the study. Section 1.6 presents the research questions to be investigated, offering clarity on the direction of the study. Finally, section 1.7 provides an overview of the research framework, and section 1.8 presents the thesis structure, guiding the reader on what to expect in each chapter.

1.1 Introduction

On a global scale, the construction industry's raw materials consumption and waste generation are highly unsustainable (Oyenuga & Bhamidimarri, 2015; Yeheyis et al., 2013). The sector consumes 32% of global resources, including 12% water and up to 40% energy. Approximately 40% of the raw materials extracted from the earth and 25% of virgin wood are used for construction activities (Yeheyis et al., 2013). Worldwide, Construction and Demolition (C&D) activities produce nearly 25% of solid waste, which continues to increase (Loizou et al., 2021). In developed countries with intensive building and rebuilding activities, the numbers of C&D waste are even higher. Therefore, a shift from a linear economy, useful application of materials, toward a Circular Economy (CE), extended lifespan of the product and its parts and smarter product use and manufacture, is required (Graham-Nye, 2022). Åkesson et al. (2022) argue that the transition toward CE is part of the solution to minimize natural resource consumption and maximize resource efficiency.

According to Husgafvel et al. (2022), where authors compare various areas to promote sustainability and CE, construction and buildings offer the most opportunities. While there is some emphasis on reusing and recycling materials, it is insufficient as the process is not circular where the materials can be used repeatedly, cycle after cycle, for the same function without waste, or other concepts such as rethink and reduce are being applied. For example, the Netherlands reuses a large amount of material recycled from demolition activities in civil engineering projects, often as filler or road base material. However, a negligible proportion of material not precisely known can be reused, cycle after cycle, for the same function (Schut et al., 2016).

Circular Business Models (CBMs) are essential for shifting to CE in the building sector (Leising et al., 2018). They can address the traditional business models' inefficient building practices and inefficient resource management (Rios & Grau, 2019). Considering the Business Model (BM) context, Product-Service System (PSS) can result in extended product and material use and lifecycle (Åkesson et al., 2022). PSS prioritizes customer needs and services over product sales (Tukker, 2015) and emphasizes combining products and services to optimize resource efficiency and minimize waste (Batlles-de-laFuente et al., 2021; Tukker, 2015).

Therefore, PSS is identified as one of the solutions for decoupling economic growth from resource consumption and realizing CE (Kjaer et al., 2019). In addition, studies agree that implementing PSS could result in CE practices in the building sector (Leising et al., 2018; Rios & Grau, 2019). Despite being explored as a BM for decades, companies still face many barriers to implementing PSS, especially in the building sector (Hart et al., 2019).

1.2 Problem Statement

As explained, there is a consensus that the traditional way of building and constructing based on a linear economy, according to the “take-make-dispose” principle, is unsustainable (Acharya et al., 2018), and a transition towards a CE is necessary (Adams et al., 2017; Rios & Grau, 2019). To accomplish this, attention must be paid to the long-term status of a building, and to facilitate the long-term outlook, the application of the PSS is a possible solution (Aguerre et al., 2018; Hart et al., 2019; Rios & Grau, 2019). The industry is willing to shift to servitization and service-oriented offerings; however, companies need clarity on the transformation and factors driving or impeding the transition (Kroon, 2020). ***Companies face barriers to implementing service-oriented BM, especially in the building sector, resulting in additional uncertainties and challenges for the already complex task.*** Therefore, to enable companies in the building sector to adopt PSS successfully, it is necessary to understand the current state of the art of PSS, assess the barriers, and identify potential solutions to overcome them.

1.3 Research Gap

Research and studies have focused on C&D waste (Loizou et al., 2021; Oyenuga & Bhamidimarri, 2015; Yeheyis et al., 2013), CE in the construction sector (Leising et al., 2018; Schut et al., 2016; Transition Agenda Circular Economy, 2018), its challenges, barriers, and drivers (Adams et al., 2017; Hart et al., 2019; Kanters, 2020), factors affecting circularity of building materials (Kroon, 2020; Sagan & Sobotka, 2021), and CBMs (Antwi-Afari et al., 2021; Munaro et al., 2021; Ünal et al., 2019). Studies have also researched the implementation of PSS as a promising approach toward a CE (Barquet et al., 2016; Ceschin, 2014; Kjaer et al., 2019). However, compared to linear economic BMs, the knowledge about PSS is limited and fragmented, especially regarding the barriers that companies in the building sector face in transitioning to PSS and their potential solutions.

There is a lack of comprehensive studies focusing on PSS barriers and solutions for companies implementing it in the building sector. At the time of this study, there were several studies on PSSs and their barriers. However, the studies in the building sector are concentrated on a particular set of PSS barriers or systems, and less attention is paid to how to overcome these barriers. For example, Kuipers (2021) has identified financial, legal, and organizational barriers to implementing PSS BM in the Dutch built environment. Hence, there is a need to review and combine the available knowledge to assess the current state of PSS and identify barriers to PSS and their potential solutions in the building sector.

1.4 Research Objectives

This study aims to analyze PSS's current state of the art, focusing on the building sector, and identify the barriers that hinder their adoption. The primary objective is to provide a comprehensive overview of these barriers and link them to potential solutions companies could implement to overcome them. Furthermore, the study seeks to highlight the significance of PSS

and the importance of adopting PSS principles to promote circularity and sustainability in the building sector. Ultimately, the findings of this study are expected to contribute to the literature and practice of PSS and CE, enabling contractor companies to adopt sustainable practices and positively impact the industry.

1.5 Research Scope

This study considers PSS in the building sector from the contractor companies' perspectives active in the European Union construction market. The company's perspective is essential because the providers' part of the task is more complex, and there are more responsibilities on the providers' side with PSS, resulting in more challenges. The research will target applying PSS in residential and non-residential buildings because they account for a significant portion of the construction sector and are typically constructed, serviced, and maintained by companies of various sizes, large, medium, and small. The study will use the available scientific literature and semi-structured interviews to fulfill the research objectives. Elaboration on the literature review and interview methods and the inclusion and exclusion criteria are provided in the methodology chapter of this study. The following two paragraphs briefly introduce CE and PSS in the context of this study.

CE is an economic model that seeks to reduce waste and increase resource efficiency by keeping materials and products at the highest value and utility for as long as possible, considering a system perspective, and utilizing practices such as refuse, rethink, reduce, reuse, repair, refurbish and recycling (Kirchherr et al., 2017). The objective is to use existing products and materials better, recover and reuse them at the end of their useful life, and ensure sustainable practices (Geissdoerfer et al., 2017; Kirchherr et al., 2017).

In the context of CE, the PSS BM is an innovative approach that has gained traction, combining products and services to meet specific customers' needs while adding value throughout the product lifecycle. PSS emphasizes service provisioning over only selling products, seeking to reduce waste and optimize resource efficiency. Contractor companies applying this model may transition from linear take-make-waste practice to a circular reduce-reuse-recycle approach providing customers with a more sustainable and efficient alternative over traditional product-based consumption. PSS benefits the producer, users, and the environment as it has lower environmental effects than product-only systems (Tukker & Tischner, 2006). PSS implementation improves efficiency, allowing for reuse, recycling, and waste reduction, and helping companies expand their market share, answer customers' expectations, and create longer relationships (Batlles-delaFuente et al., 2021).

1.6 Research Questions

This study examines the current state of PSS, identifies barriers to PSS that companies face, and provides potential solutions to the recognized barriers. Considering these objectives, the following main research question is formulated.

Main research question: How can contractor companies overcome the barriers to Product-service system business models in the building sector?

The following sub-questions are formulated to address the main research question. In addition, each sub-question is explained, and its objectives are discussed.

Sub-question 1: What is the state of the art of PSS in the building sector based on scientific literature?

The study uses the available literature to assess the state of PSS, including PSS origin, definitions, classification, circularity and sustainability aspects, potential benefits, and challenges to understand the background and context of the study topic. The aim is to review and synthesize the existing PSS literature and help answer the main research question.

Sub-question 2: What is the current state of PSS adoption by companies in the building sector in practice?

The aim is to determine whether companies in the building sector currently or intend to offer PSS, moving from product-oriented BM to product-service-oriented ones. The inquiry seeks to understand the underlying reasons and motivation driving these companies to make the shift resulting in a better understanding of the barriers and potential solutions. It is essential to mention that interviews are conducted in addition to the primary research method of a literature review to support the findings.

Sub-question 3: What are the barriers to PSS?

This part aims to identify the barriers of PSS from both literature and practice in different categories that could hinder the uptake of this BM, the criticality of the identified barriers based on the available literature and practice, and which barriers contractors could manage and mitigate. In addition to providing an inventory of PSS barriers for companies, this part help in specifying the focus of the last research question, as providers do not have control over everything, such as changing the legal system or the client's willingness; therefore, they cannot alleviate all the barriers.

Sub-question 4: What are potential solutions to the identified barriers of PSS?

The objective is to identify the drivers of adopting PSS and potential solutions to overcome the barriers faced by companies in the building sector when shifting to PSS. The literature review and interviews with industry experts are applied for this part. It is essential to mention that this section only focuses on the barriers specified in sub-question 3. The result concerning potential solutions is present in a matrix diagram to visually link each barrier with the corresponding solution(s).

1.7 Research Framework

This section offers a concise yet comprehensive overview of the research framework developed to address the main research question, as depicted in Figure 1. The figure presents a clear and succinct representation of the research design, including the research and data collection methods, input, analysis techniques, and expected outcomes. It is essential to note that the research methodology is discussed in detail in Chapter Two, and this section aims to aid readers in navigating the report more efficiently.

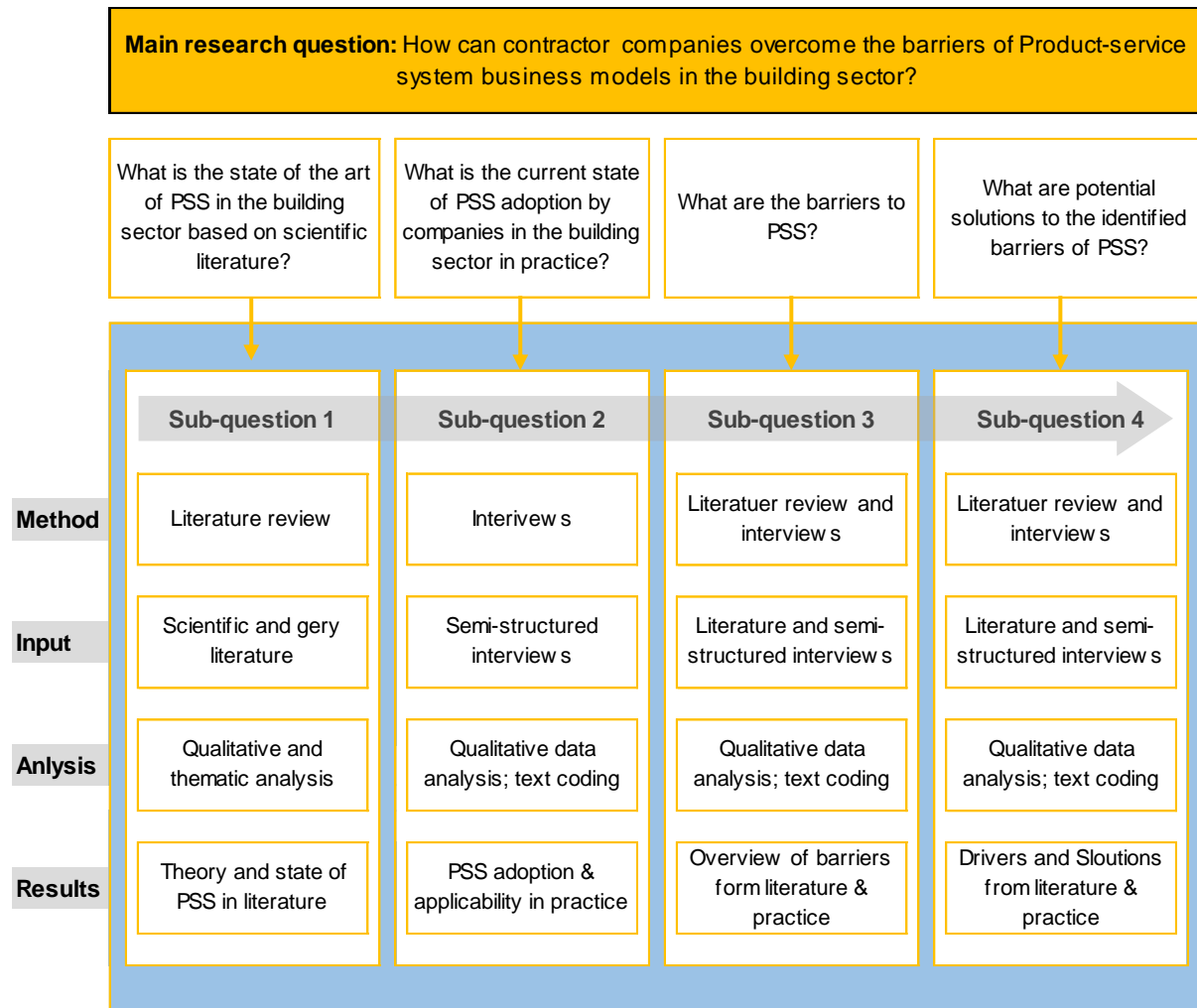


Figure 1: Research framework explaining research method, input, analysis technique, and results per sub-question: own figure.

1.8 Thesis Report Structure

As shown in Figure 2, the thesis report consists of three main parts.

Part 1 – Context and Methods

- Chapter 1 sets the stage for the study by introducing the thesis and providing context for the broader theme. The chapter defines the study's scope and objectives and lists the research questions.
- Chapter 2 describes the research methods used in the study, including the rationale for selecting the methods. In addition, the chapter explains how the data were collected and analyzed to answer the research questions.

Part 2 – The research and findings

- Chapter 3 analyzes and summarizes the research findings for sub-question one and two. It examines the current state of PSS in the building sector based on scientific literature and determines the current state of PSS adoption by companies in the building sector in practice, respectively.

- Chapter 4 analyzes and summarizes the research findings for sub-question three. It identifies the barriers to PSS in the building sector from scientific literature and interviews, provides a list of them for companies, and identifies barriers that companies can overcome.
- Chapter 5 analyzes and summarizes the research findings for sub-question four, which seeks the drivers of PSS and potential solutions to the identified barriers of PSS, using both literature and interviews.

Part 3 – Capping off the research

- Chapter 6 discusses the research findings, describes the study's implications, and acknowledges the study's limitations.
- Chapter 7 summarizes the study's main conclusion and makes recommendations for practice and further research.

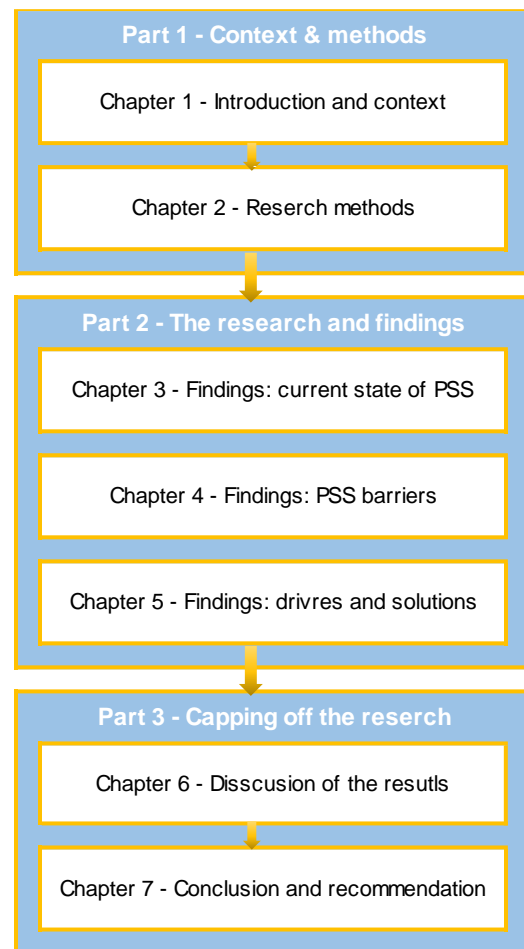


Figure 2: Structure of this report; own figure.

This chapter outlines the research method and data-gathering process used in this study and consists of two sub-sections. Section 2.1 explains the research methods to answer the research question and achieve the study objectives. Section 2.2 describes the data sources and collection methods.

2.1 Research Method

This study used a qualitative research methodology to fulfil its objectives. Qualitative research focuses on the context where researchers can understand the setting and how entities behave in those settings. The method is flexible (Sallee & Flood, 2012) and more descriptive, giving rise to surprising facts and findings, challenging yet stimulating (Dana & Dumez, 2015). This study conducted a literature review since service-oriented products are barely implemented in the building sector and semi-structured interviews to support the review findings. The following sections elaborate on the literature review and interviews.

2.2 Data Gathering

Data collection for this study involved desk research and interviews, examining available literature and participants' experiences to gather valuable supporting data.

2.2.1 Literature Review

There are various literature review methods (Paré & Kitsiou, 2017). The selection of a specific method depends on the research problem and approach. The following paragraph briefly describes the review method applied in this study.

A systematic review is a structured method that critically appraises and synthesizes all empirical evidence that complies with predefined eligibility criteria to address a well-formulated research question. In contrast, a narrative review synthesizes what has been written on a particular topic without generalizing or accumulating knowledge, and a scoping review shows the volume of literature and studies available on a specific topic. The systematic review technique is highly focused and applies to narrowly formulated research questions supported by a transparent methodology that aims to minimize bias. In comparison, a narrative review does not involve a systematic literature search and focuses on a subset of literature that could be a crucial source of bias. A scoping review does not provide a critically appraised and synthesized answer to a specific question, and it is for broader research questions that have exploratory forms. Furthermore, systematic reviews include a highly rigorous literature search and are reproducible (Munn et al., 2018; Paré & Kitsiou, 2017).

Given this study's objectives, the systematic review is a suitable method. Compared to other literature review methods, systematic review requires a careful process (Paré & Kitsiou, 2017). It entails applying scientific techniques to reduce subjectivity and bias, i.e., “systematic and

random errors”. Furthermore, the approach is formal and repeatable (Munn et al., 2018; Paré & Kitsiou, 2017; Turney, 2022).

This study uses the Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) approach to conduct the review. PRISMA was selected because previous studies have shown that review articles published in leading journals did not meet the scientific criteria (Mulrow, 1987). In 1999, an international group developed the QUOROM Statement (Quality of Reporting of Meta-analysis) guidelines to improve the shortcoming. It was a set of recommendations aimed at helping researchers produce high-quality reports (Moher et al., 1999). In 2009, the guideline underwent revision to incorporate advancements in the science of systematic reviews and was renamed (PRISMA). However, upon analyzing the transparency of published review reports, studies revealed that elements of PRISMA 2009 were frequently reported as incomplete. The PRISMA 2020 statement was updated in March 2021 to keep currency and relevance in research. This statement incorporates advances in systematic review and methodology from the last decade (Page et al., 2021).

The following sub-section explains the step adopted from PRISMA 2020 guidelines for the literature review.

2.2.1.1 Inclusion Criteria

a. Phenomena of Interest

The review considered studies focused on the current state of PSS, including PSS definition, classification, circularity and sustainability aspects, potential benefits, and challenges for the companies adopting them. Furthermore, the study explored barriers to PSS and drivers and potential solutions for companies providing PSS in the building sector.

b. Context

This review considered studies in developed countries, especially European Union countries, focused on PSS and the elements mentioned in the phenomena of interest section.

c. Types of Studies

This review considered studies focused on PSS's current state of the art and its barriers and solutions. Articles, reviews articles, conference papers, conference reviews, and book chapters were included from the Scopus database, and any type of studies was included from the Google Scholar search engine. Only studies in English with a lower date limit of 2010 were included. The reason for having the time limit is that applying the search terms using the criteria mentioned in Table 2 in the Scopus database resulted in 367 documents. When the same criteria were used without including documents after 2010, the search resulted in 379 papers showing that most of the studies were produced after 2010, as illustrated in Figure 3. The same is true with Google Scholar. Moreover, the aim was to focus on the current studies.

2.2.1.2 Information Sources

For this study, a comprehensive literature search was conducted using the Scopus database, one of the most extensive multidisciplinary abstract and citation databases of peer-reviewed literature, and the Google Scholar Web search engine. It was expected to find many studies on PSS since the database and the search engine cover multidisciplinary research studies. The search techniques enabled a systematic search and ensured that relevant PSS papers were included in the review, offering significant insights into the topics.

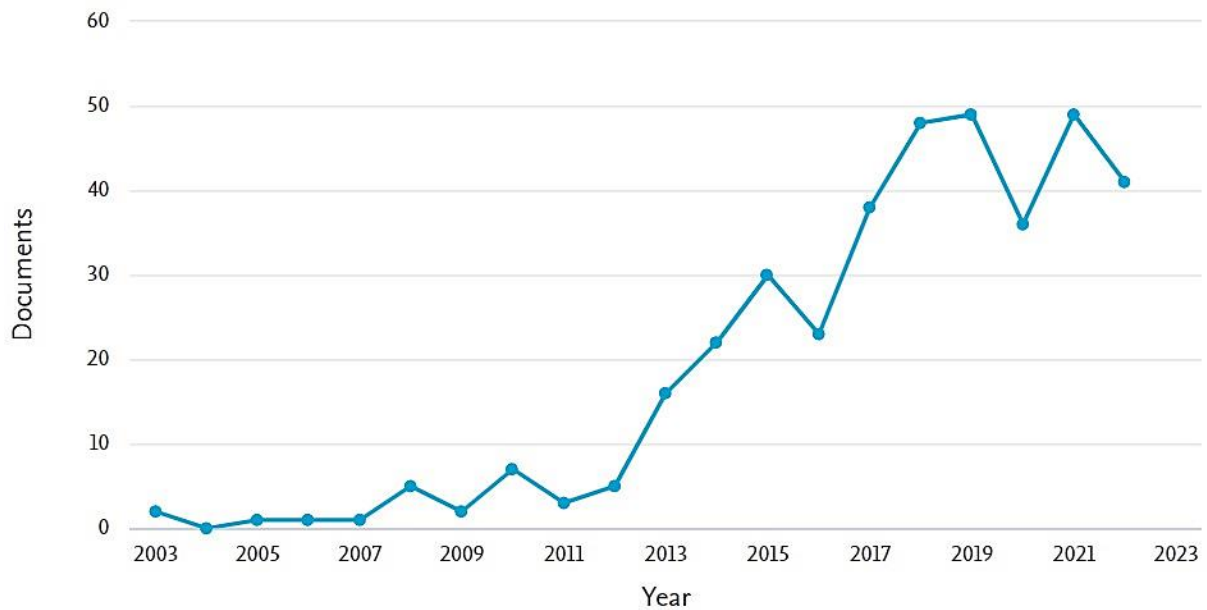


Figure 3: The number of documents by year in the Scopus database using the search term (“Product service system” AND “circular economy” OR circularity OR sustain* AND develop* OR build* OR construct* OR residential OR non-residential AND barrier* OR enabl* OR “business model”) on 8th November 2022; own figure.

2.2.1.3 Search Strategy

As visualized in Figure 4, the search included scientific literature from Scopus and Google Scholar. This review used a two-step process. First, a limited literature search was conducted using Google Scholar and followed by analyzing the text words that resulted in selecting the search terms such as product-service system, product-as-a-service, product-service, service-oriented models, business model, circular business model, barriers, enablers, solutions, drivers, circularity, circular economy, sustainability, building, construction, development, residential buildings, non-residential buildings, stakeholders and so on. Then each search term and its various combinations were used, and the results were recorded and compared to understand which terms and combinations generate the most relevant results. Once the search terms were selected, they were used to search for literature in Scopus and Google Scholar. The Google Scholar search was conducted using the advance search function. The review included studies in the English language from 2010 to 2022, searched on November 08, 2022. An overview of the search words and filter criteria for the Scopus database is shown in Table 2, and the Google Scholar search engine is shown in Table 3. The final search terms included *product service system, circular economy, circularity, sustain, develop, build, construct, residential, non-residential, barrier, enabler, and business model*. The complete search strategy is provided in Appendix I – Search Terms and Criteria.

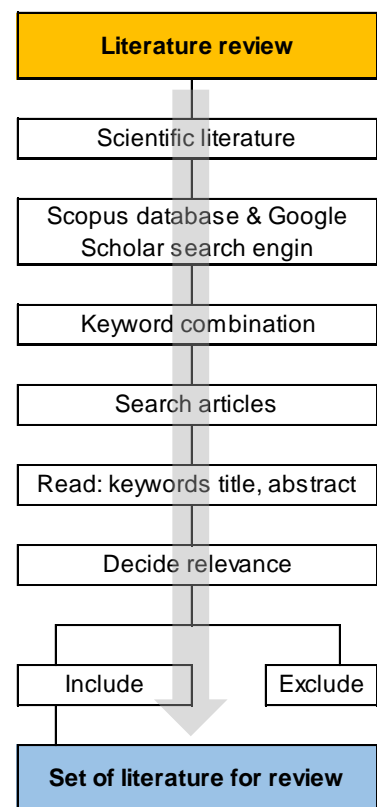


Figure 4: The process of selecting the literature for review; own figure.

Table 2: Scopus database search criteria.

| Electronic database | Scopus |
|---------------------------|--|
| Publication Type | Journal articles, review articles, conference papers, conference reviews, and book chapters |
| Subject area | Any |
| Search words | Product service system, circular economy, circularity, sustain, develop, build, construct, residential, non-residential, barrier, business model |
| Search field | Title, Abstract, Keywords |
| Language | Only papers in English |
| Other filters or criteria | Papers exclusively dealing with PSS and their barriers and enablers Articles with title, author, and publication year |
| Publication date | Studies before 2010 are excluded |

Table 3: Google Scholar search engine search criteria.

| Search engine | Google Scholar |
|---------------------------|--|
| Publication Type | Any |
| Subject area | Any |
| Search words | Product service system, circular economy, circularity, sustain, develop, build, construct, residential, non-residential, barrier, business model |
| Search field | Anywhere |
| Language | Only papers in English |
| Other filters or criteria | Papers exclusively dealing with PSS and their barriers and enablers Articles with title, author, and publication year |
| Publication date | Studies before 2010 are excluded |

2.2.1.4 Selection Process

The comprehensive literature search using both Scopus and Google Scholar resulted in a total of 767 studies that were collected and uploaded into EndNote 20. As the search included studies from two databases, this result included duplicated studies. After removing duplicates (58 documents), studies without publication year (16 documents), and without author names (12 documents), the number of studies for the screening process was reduced to 681. The screening process involved reviewing the title, abstracts, and keywords parts of the studies against the inclusion criteria, which was done using Microsoft Excel. The screening process resulted in eliminating 561 studies that were irrelevant to the research objectives.

Fortunately, all the studies included were retrieved, and any uncertainties regarding the relevance of the studies were mitigated by the full-text review of the studies. After screening, the remaining studies underwent a full-text review to ascertain their relevance. During this step, 78 studies were excluded due to non-compliance with the inclusion criteria, leaving 42 studies for inclusion in the literature review.

Additionally, seven studies were identified through citation analysis of relevant studies and were subjected to the screening process, including three additional studies. The combined

literature search results yielded forty-five studies in the final review, a list of which is presented in Table 4.

The rigorous literature search and review approach ensured that the final review contained only high-quality studies that met the inclusion criteria. The method improves the findings' reliability and validity and the results' trustworthiness. Figure 5 illustrates a comprehensive depiction of the process, followed by a complete list of the studies included in the review, presented in Table 4.

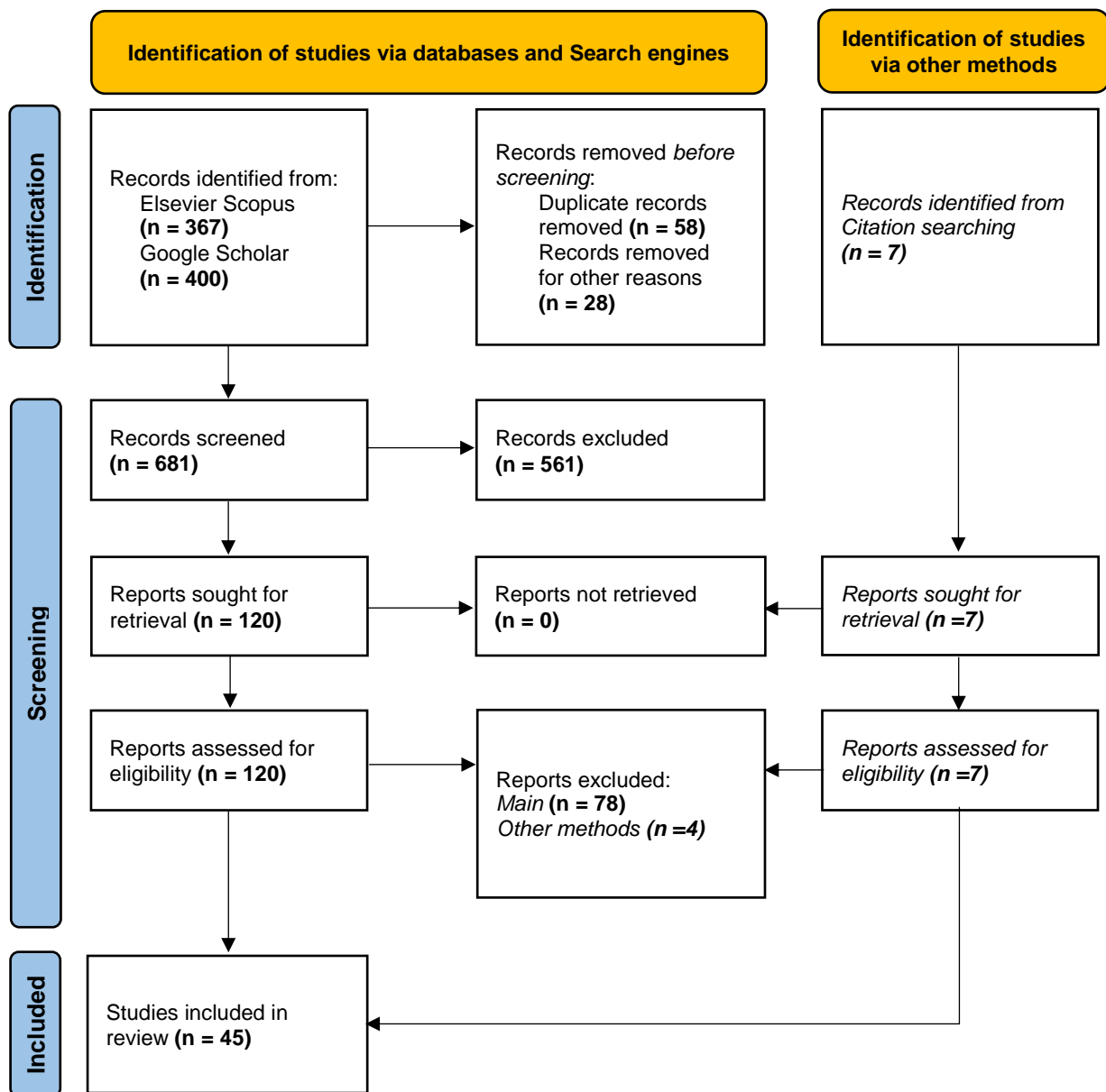


Figure 5: PRISMA 2020 flow diagram for new reviews; adapted from Page et al. (2021).

2.2.1.5 Studies Included in the Review

Table 4 lists all the studies included in the review and provide information about them, such as the type of reference (e.g., journal article, conference proceedings) and the title of the studies. To enable cross-referencing and optimize table space, the numbering in Table 4 aligns with the citations of the barriers listed in Table 11 of Chapter Four and Table 15 of chapter five.

Table 4: Studies included in the literature review.

| # | Reference type | Title | Citation |
|----|------------------------|--|---|
| 1 | Conference Proceedings | Extracting the relationship between product-service system features and their implementation barriers based on a literature review | (Inagaki et al., 2022) |
| 2 | Journal Article | From goods to services and from linear to circular: The role of servitization's challenges and drivers in the shifting process | (Hidalgo-Carvajal et al., 2021) |
| 3 | Journal Article | Product-service system innovation: A promising approach to sustainability | (Ceschin, 2014) |
| 4 | Thesis | The configurations of inhibiting and stimulating factors in servitization | (Kroon, 2020) |
| 5 | Conference Proceedings | State-of-the-Art in Product-Service System Classification | (Salwin & Kraslawski, 2020) |
| 6 | Conference Proceedings | Sustainability Factors for PSS Business Models | (Barquet et al., 2016) |
| 7 | Journal Article | Exploring servitization in industrial construction: A sustainable approach | (Galera-Zarco & Campos, 2021) |
| 8 | Journal Article | Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption? | (Kjaer et al., 2019) |
| 9 | Journal Article | Demand pull' government policies to support Product-Service System activity: The case of Energy Service Companies (ESCos) in the UK | (Hannon et al., 2015) |
| 10 | Journal Article | New design challenges to widely implement 'Sustainable Product-Service Systems' | (Vezzoli et al., 2015) |
| 11 | Journal Article | Product-service system business model archetypes and sustainability | (Yang & Evans, 2019) |
| 12 | Journal Article | Overcoming barriers towards Sustainable Product-Service Systems in Small and Medium-sized enterprises: State of the art and a novel Decision Matrix | (de Jesus Pacheco et al., 2019) |
| 13 | Journal Article | Product-service systems benefits and barriers: an overview of literature review papers | (Moro et al., 2020) |
| 14 | Journal Article | Coping with the knowledge sharing barriers in product service systems design | (Bertoni & Larsson, 2010) |
| 15 | Journal Article | Barrier analysis for product service system using interpretive structural model | (Kuo et al., 2010) |
| 16 | Journal Article | Exploring the challenges for circular business implementation in manufacturing companies: An empirical investigation of a pay-per-use service provider | (Sousa-Zomer et al., 2018) |
| 17 | Journal Article | Product-Service Systems (PSS) business models and tactics - A systematic literature review | (Reim et al., 2015) |
| 18 | Conference Proceedings | Supporting Sustainable Product-Service System Implementation through Distributed Manufacturing | (Petruilaityte et al., 2017) |
| 19 | Conference Proceedings | Design for sustainable behaviour in product/service systems - A systematic review | (Gustafsson et al., 2021) |
| 20 | Journal Article | Business models towards SDGs: the barriers for operationalizing Product-Service System (PSS) in Brazil | (Labbate et al., 2021) |
| 21 | Journal Article | Sustainable product-service systems and circular economies | (Hernandez, 2019) |
| 22 | Journal Article | Sustainable business model in the product-service system: Analysis of global research and associated eu legislation | (Batlles-de-laFuente et al., 2021) |
| 23 | Journal Article | Exploring barriers to implementing product-service systems for home furnishings | (Schoonover et al., 2021) |
| 24 | Journal Article | Façades-as-a-Service: The Role of Technology in the Circular Servitisation of the Building Envelope | (Azcarate-Aguerre, Klein, et al., 2022) |

| | | | |
|----|------------------------|---|--|
| 25 | Conference Proceedings | Exploring Challenges to Design Product-Service Systems in SMEs-A Case Study | (Åkesson et al., 2022) |
| 26 | Book Section | Facades-as-a-Service: a business and supply-chain model for the implementation of a circular façade economy | (Azcarate-Aguerre, Andaloro, et al., 2022) |
| 27 | Journal Article | Transformation of a small-to-medium-sized enterprise to a multi-organisation product-service solution provider | (Clegg et al., 2017) |
| 28 | Journal Article | Receptivity to the production of product service systems in the UK construction and manufacturing sectors: A comparative analysis | (Cook et al., 2012) |
| 29 | Book Section | New business for old Europe: product-service development, competitiveness and sustainability | (Tukker & Tischner, 2017) |
| 30 | Journal Article | STATE OF THE ART OF PRODUCT SERVICE SYSTEM DEVELOPMENT APPROACHES | (KRETSCHMAR, 2021) |
| 31 | Journal Article | Drivers and barriers to the delivery of integrated Façades-as-a-Service | (Aguerre et al., 2018) |
| 32 | Journal Article | When do circular business models resolve barriers to residential solar PV adoption? | (Van Opstal & Smeets, 2022) |
| 33 | Journal Article | Designing and Evaluating Energy Product-Service Systems for Energy Sector (EPSS) in Liberalized Energy Market: A Case Study in Space Heating Services for Japan Household | (Kusumaningdyah et al., 2019) |
| 34 | Journal Article | Product services for a resource-efficient and circular economy- a review | (Tukker, 2015) |
| 35 | Journal Article | Switch the channel: Using cultural codes for designing and positioning sustainable products and services for mainstream audiences | (Santamaria et al., 2016) |
| 36 | Journal Article | Circular Business Model Innovation: Inherent Uncertainties | (Linder & Williander, 2017) |
| 37 | Journal Article | Critical factors for implementing and diffusing sustainable product-Service systems: Insights from innovation studies and companies' experiences | (Ceschin, 2013) |
| 38 | Journal Article | A classification model for product-service offerings | (Gaiardelli et al., 2014) |
| 39 | Journal Article | Product service system transition method: building firm's core competence of enterprise | (Chiu et al., 2019) |
| 40 | Conference Proceedings | Value drivers in product-service systems: An empirical study of two sharing business models | (Moro & Cauchick-Miguel, 2021) |
| 41 | Journal Article | Exploring business model innovation for sustainability: an investigation of two product-service systems | (Sousa-Zomer & Cauchick-Miguel, 2019) |
| 42 | Journal Article | Design of product-service systems: Toward an updated discourse | (Lugnet et al., 2020) |
| 43 | Conference Proceedings | Towards the Management of the Development of Product-Service Systems in Business Ecosystems - State-of-the-Art | (Humbeck et al., 2019) |
| 44 | Conference Proceedings | Sustainability Driven Product-Service Systems Development: A Case Study in a Capital Goods Manufacturing Company | (Sarancic et al., 2022) |
| 45 | Journal Article | Product service system: A conceptual framework from a systematic review | (Annarelli et al., 2016) |

2.2.1.6 Data Collection Process

The author extracted the data, comprised of specific details about the phenomena of interest from studies included in the review.

2.2.1.7 Data Items

The study searched for the origin, definitions, and classification of PSS, along with the progression of these definitions and classification and their main focus and distinctions. Besides, PSS's circularity and sustainability aspects and their potential benefits, challenges,

and drivers were explored. Furthermore, considering the companies' perspective, the study sought the barriers and solutions to PSS, especially in the building sector.

2.2.1.8 Risk of Bias

This study is an individual task; therefore, no other reviewer or researcher was involved in helping mitigate the risk of bias.

2.2.1.9 Synthesis Method

Synthesizing and interpreting qualitative findings is essential for achieving meaningful and relevant outcomes. The author collected the qualitative data related to the research question and objectives and synthesized and categorized them based on their similarity in meaning. The themes were put into categories to reflect the findings. Narratives addressing the research question and objectives were interpreted and created by synthesizing the data, resulting in reliable conclusions and recommendations. Finally, transparency and rigor were maintained throughout the process to preserve the integrity of the findings.

2.2.2 Semi-Structured Interviews

There are different types of interviews distinguished based on their level of structure. Therefore, a brief description of the selected interview method is provided.

Structured interviews have predetermined questions and ask orders. In contrast, unstructured interviews do not have predetermined questions and order, and semi-structured interviews are a mix of both. Semi-structured interview approach is a qualitative research method that depends on asking questions in a set thematic framework (George, 2022). Considering the advantages of semi-structured interviews, this study will use this type where the list of topics to discuss and a few questions are predetermined while keeping the order of the topics and questions flexible.

The interviewees for this study were selected based on their affiliation with companies in the building sector that demonstrate a commitment to sustainable practices on their websites. Specifically, contractors and consultancy companies prioritizing reducing CO2 emissions, implementing circular and sustainable practices in residential and non-residential building sectors, or offering PSS were considered for interviews. The selection criteria were aligned with the research aims and objectives.

Semi-structured interviews were conducted with professionals in the building construction sector to gather their experiences and opinions. The interviews, lasting approximately 60 minutes each, were recorded and transcribed. A denaturalized approach was employed during transcription to capture the interviewees' insights, ensuring accuracy in representing their perspectives. The resulting transcripts, which underwent language and grammar review, served as a valuable data source for the literature review, providing detailed and reliable responses to support the study.

Table 5 summarizes the anonymized information about the interviews conducted, including the number of interviews, the position of the individuals within the companies, the sized and the type of the companies, and the products-services the companies offer. The companies were categorized based on the number of employees, where Small means the company has less than 50 employees, Medium from 50 to 250 employees, and Large means over 250 employees. The table also includes the interview code for in-text citation alongside the date of each interview.

Moreover, all the interviews were conducted online and in English, and the same set of interview questions was used in all the interviews. The interview protocol, including the interview questions utilized in this study, is presented in Appendix II – Interview Protocol, and the informed consent form, including the specific consent points, is provided in Appendix III – Informed Consent Form.

Table 5: list of the individuals interviewed.

| No | Actor | Company Focus | Company aim | Company size and [type] | Coding | Interview Date |
|----|--------------------------------------|---|---|-------------------------|--------|----------------|
| 1 | Sustainability manager | Facade specialist | Sustainable & Circular Façade for residential and non-residential buildings | Small Contractor | BP1 | 16/01/2023 |
| 2 | Project director | Real estate and infrastructure company | Reduction in CO2 emission and natural resource consumption | Large Contractor | BP2 | 16/01/2023 |
| 3 | Business Developer | Partition walls, glass walls, ceilings, and meeting spaces | Sustainable and circular via flexibility, modularity, and reusability. | Small Contractor | BP3 | 17/01/2023 |
| 4 | Marketing and Sustainability manager | Develop, produce, and install wall systems, doors, windows, ceilings, and interior construction | CO2-neutral building through reuse | Medium Contractor | BP4 | 18/01/2023 |
| 5 | Co-Founder/ CEO | Circular and Modular Kitchens, Kitchen-as-a-Service | Sustainability & Circular Economy: Healthy planet, CO2 reduction, and material consumption. | Small Contractor | BP5 | 20/01/2023 |
| 6 | Senior Advisor: Circular Building | Housing constructions | CO2 reduction, Sustainable and Circular construction. | Large Contractor | BP6 | 20/01/2023 |
| 7 | Project manager | Consultancy, real estate, and infrastructure | Reduction in CO2 emission and natural resources consumption | Large Consultancy | BP7 | 23/01/2023 |
| 8 | Co-founder/ consultant | Transparent walls (glass walls) | Transition to a circular economy in building construction. | Small Consultancy | BP8 | 13/02/2023 |

This chapter provides a comprehensive overview of PSS's current state of the art. It begins with an exploration of the origin of PSS in section 3.1, followed by an analysis of the various definitions of PSS in Section 3.2. Section 3.3 examines the classification of PSS and its evolution, and section 3.4 focuses on the circularity aspects of PSS. The sustainability potentials of PSS are discussed in section 3.5, and Section 3.6 covers the potential benefits of PSS. Section 3.7 highlights the challenges of PSS, and finally, section 3.8 presents an analysis of PSS implementation in the building sector using the six-layer model of a building.

3.1 The Origin of PSS

This section provides a brief overview and context of PSS as it is gaining traction as a practical and effective means to achieve sustainability (Inagaki et al., 2022). PSS has the potential to decouple economic growth from resource consumption (Baines et al., 2007; Kjaer et al., 2019), and today, where sustainable development is of utmost importance for building a better future, adopting PSS is crucial (Labbate et al., 2021). However, the significant aspect to emphasize is that a PSS, if properly conceived, can decouple economic value from material consumption (Manzini & Vezzoli, 2003; Mont, 2002; Tukker & Tischner, 2006), which is called an eco-efficient PSS (Ceschin, 2013). PSS was coined by combining the following four concepts.

3.1.1 Eco-efficient Services

Eco-efficient services refer to product-service combinations or systems that offer maximum added value while causing minimal adverse environmental impacts (Brezet et al., 2001). Eco-efficient services strive to increase consumption efficiency when creating, using, and consuming products while providing the same level of services with reduced negative environmental impacts (Galera-Zarco & Campos, 2021). It encourages sharing economy, allowing a single product to serve multiple users and reducing the materials needed to meet customer demands (Ceschin, 2013).

Brezet et al. (2001) reasons that the concept of PSS is not new as all products and services are part of systems; however, the new notion is that companies should consider the system when innovating. Developing eco-efficient service implies intentionally designing a PSS to minimize negative environmental impact per added value unit, and prioritizing services over products enhances eco-efficiency at functional and systemic levels. (Brezet et al., 2001).

3.1.2 Dematerialization

Dematerialization involves using fewer raw materials and energy to produce the same result (Kroon, 2020). Companies use this strategy to cut costs by utilizing fewer raw resources and decreasing waste. For example, this concept is used in cars and computers, resulting in lighter products with improved functionality. Therefore, with product plus service or PSS, the same number of products can meet more people's needs (Yang & Evans, 2019), expanding the possibilities of dematerialization (Brezet et al., 2001).

In the past, companies primarily relied on product sales to generate revenue. They started to search for strategies to expand their business, increase profits and market share, and become more competitive. Some thriving companies adopted the concept of providing integrated packages of products and services to better serve their customers' needs, an approach known as business servitization (Batlles-delaFuente et al., 2021).

3.1.3 Servitization

Servitization is adding service to traditional product-based offerings (Galera-Zarco & Campos, 2021; Kroon, 2020) and focusing on transitioning to service (Mont, 2002). PSS is part of servitization or service economy as it combines product and service. According to the introducer of servitization Vandermerwe and Rada (1988), it is moving toward combining products, services, support, knowledge, and self-service, as shown in Figure 6. This approach involves collaboration with customers to co-create and co-develop solutions ranging from basic to comprehensive service offerings (Galera-Zarco & Campos, 2021). Implementing servitization consists in reviewing and changing the organizational structure and business processes. Risk increases as the level of service advances (Batlles-delaFuente et al., 2021), and successful adoption of technology is crucial for effective implementation (Batlles-delaFuente et al., 2021; Galera-Zarco & Campos, 2021). Servitization allows for long-term relationships between manufacturers and customers, increasing manufacturer profitability and customer loyalty (Batlles-delaFuente et al., 2021; Kroon, 2020).

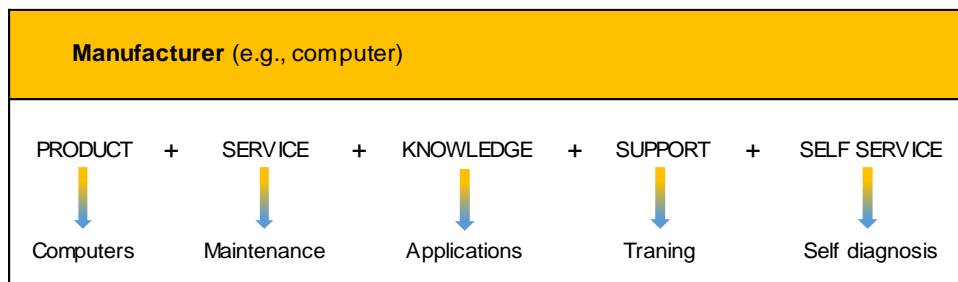


Figure 6: An example of servitization that includes the combination of product, service, support, knowledge, and self-service; adapted from Vandermerwe and Rada (1988).

In conventional business thinking, profit centers are tied to physical products. The goal is to sell products, ancillary components, and spare parts as much as possible and minimize expenses. Producers strive to reduce material and energy consumption during production but do not have any financial interest in lessening consumption or minimizing waste during use. In some cases, the producers may even benefit from selling products with a limited lifespan to prompt frequent replacements. Alternatively, when offering a service or performance that is paid based on the service provided or the function performed instead of the units sold, producers and customers have the financial incentives to reduce the use of resources and optimize their usage (Ceschin, 2014). The servitization approach addresses the strategic desire of manufacturers and producers to enhance their BMs. That results in new revenue streams and improved customer satisfaction through highly valued services besides their current product-related revenue-generating activities. Therefore, serviced businesses typically offer PSSs, whereas non-serviced firms only provide products (Clegg et al., 2017). PSS is often used to explore servitization, emphasizing the importance of offering comprehensive solutions to customers (Batlles-delaFuente et al., 2021). The above-stated has made buying products irrelevant to customers and drew attention to the functional economy (Yang & Evans, 2019).

3.1.4 Functional Economy

The notion of functional sales changes the entire meaning of value. With traditional sales, producers are value creators, while customers are value destroyers (Batlles-delaFuente et al., 2021; Ceschin, 2014). However, in a functional economy, producers are value providers, and clients are value users. Both sides want to ensure continuous service delivery and value provisioning (Batlles-delaFuente et al., 2021). In contrast to regular sales, where there is a clash of interests between producers and consumers, these interests could be better aligned in functional sales. In traditional sales, the producers try to sell more products, ancillary components, and spare parts, while consumers strive to minimize the costs of these products (Ceschin, 2014). Therefore, providers do not have any reason to ensure the user takes good care of products, as lack of care can lead to early obsolescence and prompt replacement, resulting in new purchases. On the contrary, functional sales can help align the interests of producers and customers, incentivizing providers to minimize traditional sales' drawbacks. For instance, if the offering is a performance or a service (e.g., HVAC-as-a-service), providers are economically well-off to reduce materials and energy consumption in both the manufacturing and use phase which could encourage less expensive usage conditions, longer product lifecycle, reusing and refurbishing components, and recycling materials (Ceschin, 2014).

The classic economy relies on money exchanging hands at purchase, called the “river economy.” On the other hand, the functional economy evaluates success through asset management and the potential revaluation of existing products, and it could be seen as a “lake economy” with its circular structure (Ceschin, 2014).

The functional economy is central to the PSS concept and has the potential to transform our current production and consumption toward a more dematerialized approach. However, adopting PSSs alone does not guarantee environmental sustainability; proper design, development, and delivery are crucial for success (Ceschin, 2014). Although PSS is initiated from sustainability concerns, the emphasis has shifted from environmental to economic benefits (Batlles-delaFuente et al., 2021). A PSS that combines providers' economic and competitive interests while continuously seeking environmentally beneficial solutions is called an eco-efficient PSS, which incorporates financial interest and optimizing resource consumption. However, eco-efficient PSS are not always sustainable PSS. The former includes economic and environmental dimensions, while the latter also focuses on the social dimension, maximizing social well-being, equity, and cohesion (Ceschin, 2014).

3.2 Product-Service Systems

PSS has become increasingly popular since the mid-1990s due to its sustainability potential. Sustainability experts believe that focusing on satisfying the end user's needs or providing the desired service rather than selling the product can lead to the easier design of need-fulfillment systems with far reduced negative consequences. This is because product-oriented companies are better off maximizing the number of products sold, which is the primary method of increasing turnover, market share, and profits. But, in a service-oriented business, the money is paid for the service. The motive is to deliver the best service; the materials and consumables used to provide the service become cost factors (Tukker, 2015).

Consequently, PSS incentivizes companies to extend the useful life of the products, ensure extensive use and reuse of the product, elements, and materials, improve resource efficiency,

and minimize material flows. Furthermore, environmental issues boosted interest in PSS (Tukker, 2015). With the increasing global population, resource efficiency has become a necessity (Dobbs et al., 2011), and scholars and policymakers consider PSS as an essential means of building a “lease society” or a CE (Tukker, 2015).

3.2.1 Definitions of PSS

As shown in Figure 7, the phrase Product-Service System was created by combining functional economy, eco-efficient service, dematerialization, and servitization into a singular term in the 1990s (Goedkoop et al., 1999); the key elements of PSS are as follows:

Product: a manufactured tangible item intended for sale and fulfilling a user’s needs.

Service: an economically valuable activity performed for others, typically commercially.

System: a group of elements and their relations.

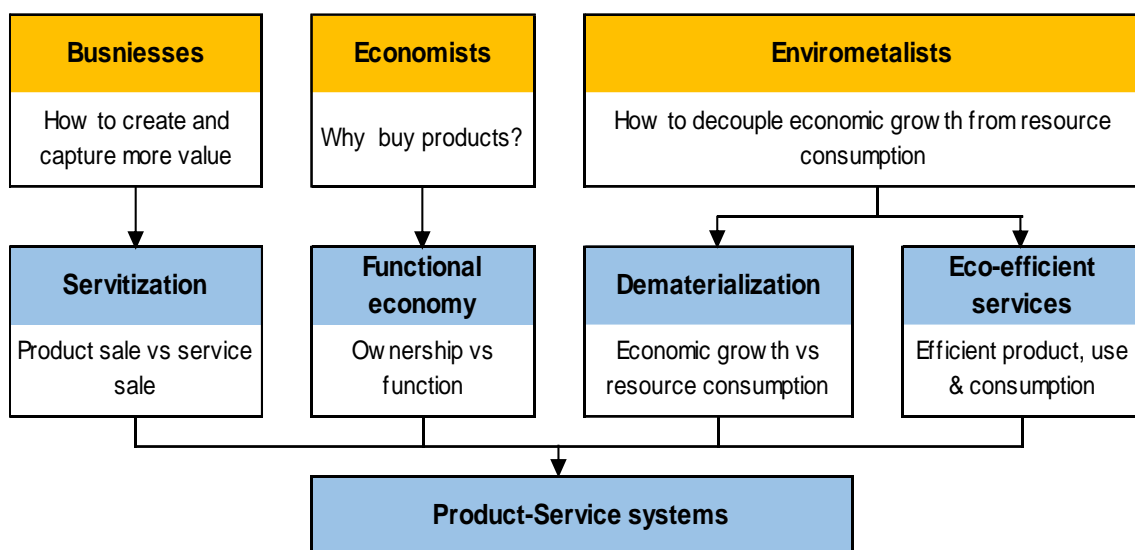


Figure 7: The origin and context of PSS: own figure.

One of the first formal definitions of PSS was presented by Goedkoop et al. (1999), “a marketable set of products and services capable of jointly fulfilling a user’s need” (p. 18). Afterward, other authors had valuable additions presented in Table 6. Manzini and Vezzoli (2003) describe PSS as an “innovation strategy” changing the focus from selling products to providing services. Another significant addition was by Mont (2002), mentioning that PSS is “a system of products, services, supporting network, and infrastructure” (p. 239). The notion of customer value generation through PSS was contributed by Baines et al. (2007). Furthermore, some authors have mentioned that PSSs have lower environmental impacts (Bodenhoefer et al., 2004; Evans et al., 2007; Mont, 2002) and could offer social benefits (Krucken & Meroni, 2006).

Compared to servitization, PSS takes things further and emphasizes the entire system associated with the service. With PSS, the providers should change from a product-centric to a system-centric approach, extending manufacturer responsibility to areas that often lie outside the buyer-seller relationship (e.g., return of materials or financing) (Kroon, 2020).

Hence, PSS is a specific value proposition that changes a firm’s focus from creating and selling physical products alone to combining product and service delivery to address a specific customer’s need. The aim is to deliver functions instead of products (Ceschin, 2014) (e.g.,

providing thermal comfort instead of air conditioning units). The concept of PSS is interesting as it has the potential to decouple value creation from resource consumption, reducing material and energy consumption (Ceschin, 2014).

Table 6: PSS definitions and their focus.

| Author(s) (Year) | Definition | Definition includes | | | | | |
|----------------------------|--|---------------------|-------------------------------------|---------------------------------------|---------------------------|----------------------|--------------------------------|
| | | Concept of system | market proposition / customer needs | Tangible product & intangible service | Network & Infrastructures | Environmental impact | Social aspects & collaboration |
| Goedkoop et al. (1999) | A marketable set of products and services capable of jointly fulfilling a user's need. The PS system is provided either by a single company or an alliance. | x | x | x | | | |
| Mont (2002) | A system of products, services, supporting networks, and infrastructure that is designed to be: competitive, satisfy customer needs, and have a lower impact than traditional business models. | x | x | x | x | x | |
| Manzini and Vezzoli (2003) | It is an innovation strategy shifting the business focus from designing and selling physical products only to designing and selling a system of products and services jointly capable of fulfilling specific client demands. | x | x | x | | | |
| Brandstotter et al. (2003) | A product of tangible and intangible services designed and combined so that both jointly are able to satisfy a specific need, it tries to reach sustainability targets. | | x | x | | x | |
| Tukker (2004) | A system consisting of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs. | x | x | x | | | |
| Wong (2004) | A solution offered for sale that involves both a product and a service element to deliver the required functionality | | x | x | | | |
| Bodenhoefer et al. (2004) | A system of products, services, supporting networks, and infrastructure designed to be: competitive, satisfy customer needs, and have a lower environmental impact than traditional business models. | x | x | x | x | x | |
| Halme et al. (2006) | Products and services which can simultaneously fulfill people's needs and considerably reduce the use of materials and energy. | | x | x | | x | |
| Krucken and Meroni (2006) | It is an advanced industrialized solution based on collaboration between social players, giving rise to effective and efficient, highly contextualized services. | | | x | | | x |
| Baines et al. (2007) | An integrated product and service offering that delivers value in use. It offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity. | x | x | x | | x | |
| Evans et al. (2007) | It is An attempt to use existing industrial and commercial structures to create radically environmentally improved products by treating them as services. | | x | x | | x | |
| Neely (2008) | An integrated product and service offering that delivers value in use. | | x | x | | | |
| Zhu et al. (2011) | A solution for optimal resource operations in the product life cycle through integrating tangible products with intangible services. | | | x | | x | |
| Geng and Chu (2012) | Products and services are integrated and provided as a whole set to fulfill customers' requirements, and the product/service ratio can vary in the different customer-using contexts. | x | x | x | | | |
| Boehm and Thomas (2013) | It is an integrated bundle of products and services aiming to create customer utility and generate value. | x | x | x | | | |
| Centenera and Hasan (2014) | It is an integrated combination of products and services for optimal consumption. | x | | x | | x | |
| McKay and Kundu (2014) | It is a system composed of a physical product and associated services that support the product through life. | x | | x | | | |

With the PSS BMs, companies profit by providing services to meet customer demands. Clients consume the functions and services that come with the product but not the product itself. The company is responsible for after-sales services such as its warranty, maintenance, upgrade, recycling, and scrapping (Kuo et al., 2010).

PSS, which involves tangible products and intangible services, is central to CE. However, PSS does not automatically lead to reduced resource use, and strategies for reducing resource consumption do not necessarily lead to sustainability improvements. Resource decoupling in CE means separating economic growth from resource consumption by increasing resource productivity, which can reduce environmental impacts (Kjaer et al., 2019). PSS has been proposed as a BM to facilitate economic growth without consuming resources; however, this is not guaranteed. PSSs can lead to increased product reuse and recycling, improving resource productivity and reducing waste generation (Batlles-delaFuente et al., 2021).

According to Hernandez (2019), several authors have mentioned that PSS can enhance environmental performance, encourage social responsibility, and create economic value. Despite that PSSs have the potential to contribute to environmental, societal, and economic sustainability, they have not yet been broadly implemented (Petruilaityte et al., 2017). However, the notion that PSS is automatically more circular and sustainable than conventional BM is invalid. PSS can offer an innovative and sustainable solution, yet, the system must be designed with that objective in mind (Hernandez, 2019).

Therefore, PSS can be both an enabler and a driver of sustainability and CE depending on the specific context and perspective. PSS is an enabler of CE and sustainability because it offers a BM that can stimulate resource efficiency, waste reduction, and the creation of closed-loops systems. In addition, it can influence consumer behavior to move toward a more sustainable consumption pattern that supports CE's goals and sustainability. Likewise, PSS can also be considered a driver of CE and sustainability as it necessitates a new method of product design, production, and consumption. It requires a transition from conventional product-oriented BMs toward service-oriented models, which can lessen the negative environmental impact of consumption and production and contribute to CE and sustainability objectives.

3.3 PSS Classification

There are several classifications of PSS available in the literature. Table 7 summarizes the proposed classifications and their focus. It represents a comprehensive overview of the various classifications of PSS from the literature in chronological order. The rest of this section discusses each of the classifications presented in the table respectively.

Table 7: PSS classification, focus, and citation counts of the studies based on Google Scholar.

| Author(s) (year), [Google Scholar citation count] | PSS Classification | | Focus |
|---|-----------------------------|--|---|
| Mathieu (2001), [933] | 1. Organizational Intensity | i. Tactic ii. Strategic iii. Cultural | Consider the nature of the offer, the organization of service maneuvers, and the impact on the company. |
| | 2. Service Specificity | i. Customer service ii. Product services iii. Service as a Product | |

| | | | | |
|-------------------------------------|--|--|---|--|
| Mont (2002), [2912] | <ol style="list-style-type: none"> 1. Product/service/combinations/substitutions 2. Service at the point of sale 3. Different concepts of product use <ol style="list-style-type: none"> a. Use oriented b. Result oriented 4. Maintenance services 5. Revalorization services | | Provides an overview of the main elements of PSS, which may provide a common term of reference while studying and designing PSSs. | |
| Oliva and Kallenberg (2003), [3464] | | Product-oriented service | End-users process oriented services | Describes the process of transforming a production company into a more service-oriented one. |
| | Transaction-based service | Basic installed base service | Professional services | |
| | Relationship-based service | Maintenance Service | Operational Services | |
| Tukker (2004), [3068] | 1. Product-oriented | <ol style="list-style-type: none"> i. Product related ii. Advice related | | The range of values a product or service provides. |
| | 2. Use-oriented | <ol style="list-style-type: none"> iii. Product lease iv. Product renting/sharing v. Product pooling | | |
| | 3. Result-oriented | <ol style="list-style-type: none"> vi. Activity management vii. Pay per service unit viii. Functional result | | |
| Uchihira et al. (2007), [24] | 1. Adjustment Expansion | <ol style="list-style-type: none"> i. Consulting ii. Customizing iii. Downtime and risk reduction | | Contacts and customer relations are essential while focusing on strategies to expand production activities. |
| | 2. Commitment expansion | <ol style="list-style-type: none"> iv. Financial risk reduction v. Social risk reduction vi. Operational Efficiency | | |
| | 3. Territory expansion | <ol style="list-style-type: none"> vii. Seamless services viii. Rich content | | |
| Neely (2008), [1861] | <ol style="list-style-type: none"> 1. Integration oriented 2. Product-oriented 3. Service-oriented 4. Use-oriented 5. Result-oriented | | More comprehensive presentation of the company's service strategies. | |
| Martinez et al. (2010), [777] | <ol style="list-style-type: none"> 1. Integration mainly transactional; some addition of peripheral services 2. Product + service delivery 3. Customization of product and service 4. Product + service co-designed; total solutions | | Analyzing the customer-supplier interaction. | |
| Fan and Zhang (2010), [19] | <ol style="list-style-type: none"> 1. Product-oriented 2. Application-oriented 3. Result-oriented 4. Integrated-oriented 5. Service-oriented | | The scope of service strategy of manufacturing companies. | |
| Clayton et al. (2012), [106] | <ol style="list-style-type: none"> 1. Integration-oriented 2. Product-oriented 3. Service-oriented 4. Use-oriented 5. Result oriented | | Understanding the creation of product and service offers. | |
| Van Ostaeyen et al. (2013), [169] | <ol style="list-style-type: none"> 1. Input-based 2. Availability based 3. Usage-based 4. Performance-based <ol style="list-style-type: none"> a. Solution-oriented b. Effect-oriented c. Demand-oriented | | The performance orientation of the dominant revenue method of the PSS and the level of integration of the components of the PSS. | |
| Gaiardelli et al. (2014), [283] | Product-oriented s | <ol style="list-style-type: none"> i. Product-related ii. Advise, training & consulting | | Help companies better understand the nature of their product-service offerings and design more effective marketing and sales strategies. |
| | Use-oriented | <ol style="list-style-type: none"> iii. Leasing iv. Renting v. Sharing vi. Pooling | | |
| | Result-oriented | <ol style="list-style-type: none"> vii. Pay-per-use viii. Outsourcing ix. Functional - results | | |
| Chiu et al. (2019), [28] | <ol style="list-style-type: none"> 1. Product-oriented 2. Use-oriented 3. Result-oriented 4. Platform-oriented | | Develop a PSS transition methodology, including transformation procedures to assist enterprises in transitioning to the PSS paradigm. | |

Mathieu (2001) proposed a classification based on service specificity and organization intensity. Service specificity is a concept that arises partially from the logic of service classifications and focuses on the nature of the offering. The author divides services into three categories: “Customer service” refers to the total quality of interaction between a seller and a customer; “product services” refer to after-sales services or technical assistance; and “service as a product” refers to services that are independent of the company's other products. On the other hand, organizational intensity, a supplementary approach to tackle the range of service maneuvers, focuses on the internal perspectives of companies and the stances they might adopt to achieve desired outcomes. Likewise, the approach is categorized into three levels: tactical, strategic, and cultural. As shown in Figure 8, the greater the intensity and specificity of the service maneuver, the greater the strategic and financial benefits, and the more intensive the service maneuver, the greater the marketing benefits are. Based on the classification, the author introduces the notion that services are more than simply an offer or a product service and uses the phrase “service maneuvers” to characterize how services may be organized (Mathieu, 2001). Mathieu's categorization establishes a foundation for understanding how services can be arranged and their impact on the company (Salwin & Kraslawski, 2020).

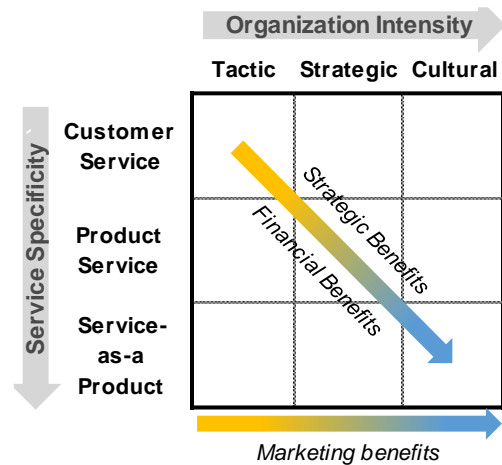


Figure 8: Typology of service maneuvers and benefits; adapted from Mathieu (2001).

Mont (2002) categorizes PSS into five main types based on combining products and services at various phases of a product's lifecycle and addressing different product-use concepts. The author provides an overview of the main elements of PSS and explains that it may contribute to a common term of reference while studying and designing PSSs.

Oliva and Kallenberg (2003) classify PSS systems by outlining the process of transforming a company into a more service-oriented one. They emphasize services required to maintain functionality throughout the lifecycle (e.g., installation, repair, improvement, decommissioning). This categorization has two organizational transformation aspects. The first step is to shift the emphasis on consumer interactions from transactional to relationship-based. The second transition shifts the focus of the end-user value proposition from product efficacy, whether the product works, to the product's efficiency and effectiveness within the end-user's process.

As illustrated in Figure 9, Tukker (2004) categorizes PSS into three main types: product-oriented, use-oriented, and result-oriented, which are further classified into eight categories based on the range of values offered by the product or service: product-related, advice and consultancy, product lease, product renting/sharing, product pooling, activity management, pay per service unit, and functional result. Moving from the first category to the last, the focus changes from products to meeting customers' abstract needs. While this allows providers greater flexibility and freedom to fulfill the actual needs of their consumers, it is often challenging to quantify the quality of the service delivered. Providers may struggle to identify their offerings, while customers may have difficulty evaluating whether their needs are met (Salwin & Kraslawski, 2020).

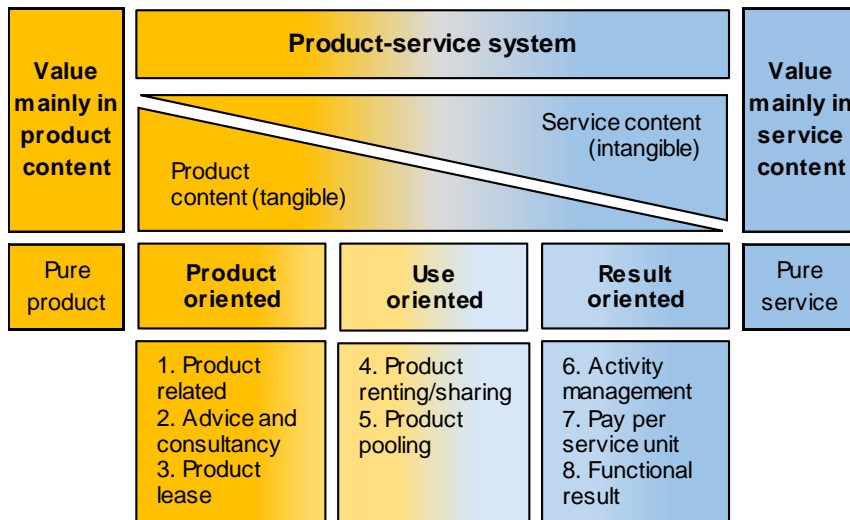


Figure 9: PSS categories and sub-categories; adapted from Tukker (2004).

Uchihira et al. (2007) presented a customer-centric approach to PSS classification known as the Customer Expansion Model. As illustrated in Figure 10, this approach identifies three types of expansion: adjustment (adjust the product to the specific needs of the customer), commitment (taking customers' risk), and territory (offer additional functions), which add value to service through improved quality (e.g., maintenance, customizing, and consulting services), reassurance (e.g., renting, leasing, and outsourcing services), and convenience (e.g., one-stop solution and service platform provider) respectively. The three categories of expansion are further subdivided into eight basic service function patterns: consulting, customizing, downtime, and risk reduction, financial risk reduction, social risk reduction, operational efficiency, seamless services, and rich content. This method gives a more detailed understanding of how services can be designed to fulfill customers' needs (Uchihira et al., 2007).

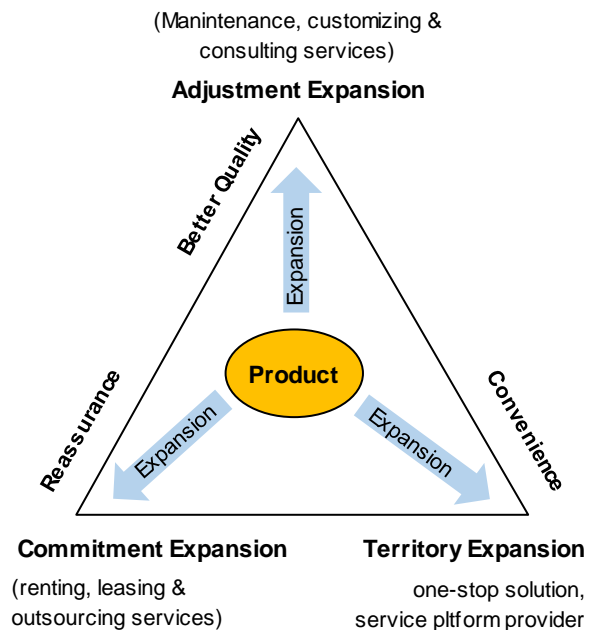


Figure 10: The customer expansion model, PSS classification, adapted from Uchihira et al. (2007).

As presented in Table 7, Neely (2008) proposed an expansion to the PSS classification of Tukker (2004). The research concluded that the PSS categorization of Tukker (2004) was inadequate to reflect the full range of companies' servicing strategies. Following Tukker (2004) criteria, Neely (2008) defined two additional PSS types: integration-oriented and service-oriented. The former involves when a firm attempts to add downstream services and introduce vertical integration, whereas the latter involves when a company integrates services into the product itself, allowing companies to deliver additional value to their customers.

Martinez et al. (2010) developed a servitization continuum closely related to PSS, defining it as a strategic innovation allowing companies to sell integrated products and service offerings. As presented in Figure 11, the servitization level of a company is assessed using four criteria, with a low level requiring minor changes and a high level requiring substantial provider and customer interaction and more support (Martinez et al., 2010).

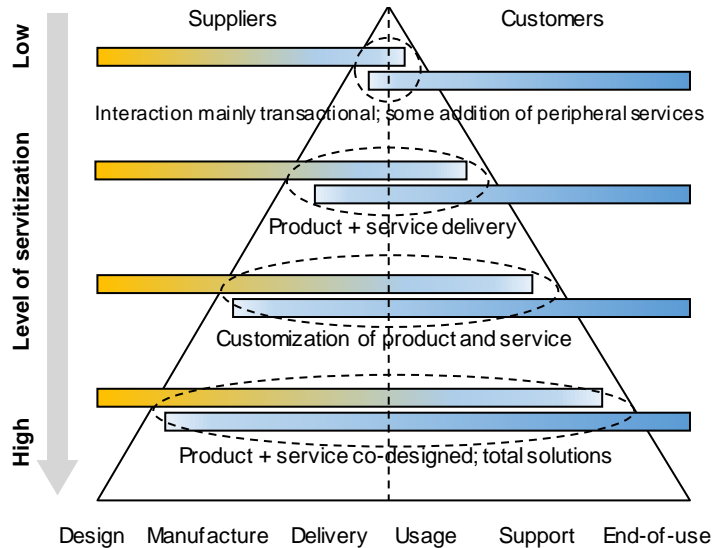


Figure 11: Servitization continuum: a view of the customer-supplier interface, broadening the interaction from transaction to relationship; adapted from Martinez et al. (2010).

Fan and Zhang (2010) established a new PSS categorization that incorporates the Tukker (2004) and Neely (2008) classifications and extends the well-known PSS types with the application-oriented approach. While establishing a PSS strategy, the new categorization considers the market environment, and the intention is to assist businesses in adapting their PSS to market dynamics and gaining a competitive edge (Fan & Zhang, 2010).

Clayton et al. (2012) have merged the five types of PSS presented by Neely (2008) into a product-service continuum ranging from pure product to pure service, as depicted in Figure 12. According to the author, a service provisioning company will not solely provide use-oriented PSS, selling functionality, or result-oriented PSS, removing the product from the offering, but will also provide a variety of business models driven by the customer's maturity.

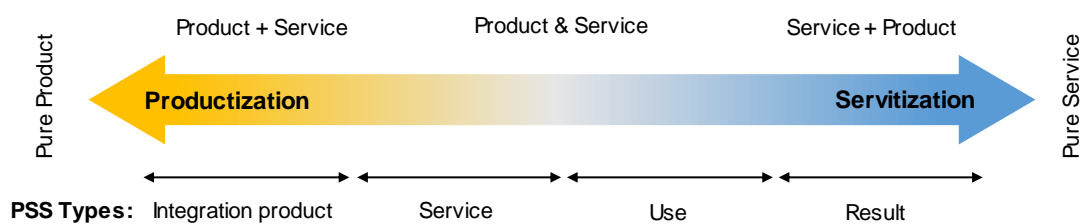


Figure 12: Continuum of product-service offerings; adapted from Clayton et al. (2012).

Van Ostaeyen et al. (2013) suggested four different types of PSS based on two distinct characteristics: the performance orientation of the dominant revenue mechanism and the level of integration between PSS elements. This typology explains the specific features that characterize PSSs, such as which products and services are included, how they are connected, and their revenue strategies. This categorization places a high value on the concept of function in PSSs.

Gaiardelli et al. (2014) propose a classification model based on the degree of integration of products and services. The authors classify product-service offerings into three types: product-oriented offerings, in which the product is the primary component, and the service is secondary;

service-oriented offerings, in which the service is the primary component and the product is secondary. And integrated offerings, in which products and services are equally important and tightly integrated. The authors also define four dimensions for further categorizing product-service offerings: (1) the level of customization, (2) the type of service provided, (3) the level of bundling, and (4) the degree of interaction between consumers and suppliers. The suggested categorization system offers a framework for comprehending and analyzing various product-service offerings.

Chiu et al. (2019) present a quantitative PSS classification framework using the rough set theory to classify PSS typology and develop a set of classification rules from analyzing 40 existent PSS service providers. The suggested PSS transition methodology involves a three-step process that considers businesses' core capabilities and current PSS types and introduces a new PSS type, platform-oriented PSS. The study advances the theoretical and practical understanding of PSS typology by presenting a systematic framework for PSS categorization and transformation. The importance of design thinking and service design tools in developing platform-oriented PSS is also emphasized. The proposed method can assist companies in their PSS transition decision-making process.

An analysis of the structure of the PSS classifications presented in Table 6 shows that it can be split into two groups. The first group of the studies focuses on offering possibilities and nature, explaining that a company's options range from pure product sales to providing services (Clayton et al., 2012; Fan & Zhang, 2010; Gaiardelli et al., 2014; Mont, 2002; Neely, 2008; Tukker, 2004; Van Ostaeyen et al., 2013). The second category focuses on transforming a company from a product manufacturer to a service provider (Chiu et al., 2019; Martinez et al., 2010; Mathieu, 2001; Oliva & Kallenberg, 2003; Uchihira et al., 2007). Furthermore, the PSS classifications available in the literature are relevant to companies of different sizes that function in various industries.

3.4 Circularity Aspects of PSS

In recent years, research into CE has attracted more interest due to its potential to alleviate sustainability challenges by changing the present production and consumption paradigm (Azcarate-Aguerre, Klein, et al., 2022). CE emphasizes eliminating waste and promoting resource efficiency through designing out pollution, extending product life, keeping materials in use, and restoring natural systems. CE can create value independent of finite resources and address the current resource scarcity. A common association between CE and the performance economy is selling services via renting, leasing, and sharing (Kjaer et al., 2019). CE aims to establish a closed-loop system where products, materials, and resources are reused, repurposed, and recycled as frequently as feasible instead of disposed of as waste (Azcarate-Aguerre, Klein, et al., 2022; Moro & Cauchick-Miguel, 2021). Therefore, it can contribute to economic, environmental, and social sustainability by reducing resource consumption and waste, stimulating economic growth, creating jobs, and promoting more equitable and resilient systems (Kjaer et al., 2019). Geissdoerfer et al. (2017) define CE as “a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops” (p. 759). According to the authors, this can be achieved through practices such as long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

In addition, PSS models focus on shifting the value proposition underlying business transactions from the transfer of products to service provisioning. In a linear economic system, the legal and economical transfer of ownership is essential, and products are used for a certain amount of time to achieve specific utilitarian results. When the product cannot offer the results or function efficiently, it is often disposed of through low-level recycling or landfilling (Azcarate-Aguerre, Andaloro, et al., 2022), resulting in “cradle-to-grave” flows (Bocken et al., 2016). However, based on the CE definition by Geissdoerfer et al. (2017) provided above, circular systems deliver value based on a regenerative process, resulting in “cradle-to-cradle” flows (Bocken et al., 2016). Figure 13 depicts the three concepts: slowing, closing, and narrowing loops in facade design and engineering. The three concepts are categories based on how much they influence resource flows' circularity (Azcarate-Aguerre, Andaloro, et al., 2022). The concepts are illustrated in Figure 14 and briefly discussed in the following paragraphs.

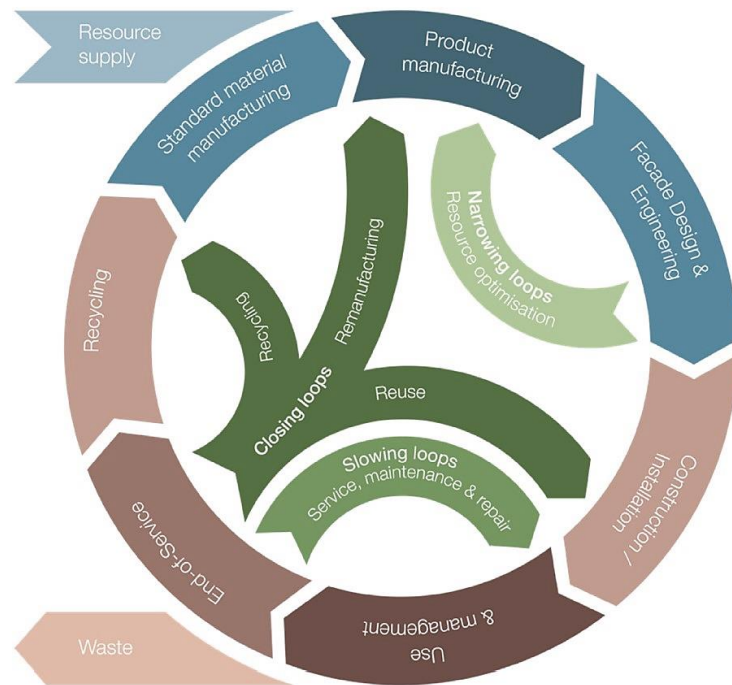


Figure 13: Narrowing, slowing and closing loops in facade design and engineering; source (Azcarate-Aguerre, Andaloro, et al., 2022).

- 1 Slowing resource loops extends the service life of products and promotes intensive utilization to slow down the pace of resource consumption through designing long-life products and designing for product-life extension (Azcarate-Aguerre, Andaloro, et al., 2022; Bocken et al., 2016). Table 8 represents product design strategies and BM strategies to slow resource loops. PSS fall into this category because they can promote the production of more durable and high-quality products, the preservation and regeneration of residual value via extended maintenance and servicing, and, as a result, the overall dematerialization of economic transactions (Azcarate-Aguerre, Andaloro, et al., 2022).
- 2 Closing resource loops is preserving resources within a regenerative system through reuse, remanufacturing, and recycling resulting in a circular flow of resources (Azcarate-Aguerre, Andaloro, et al., 2022; Bocken et al., 2016). Table 8 represents design strategies and BM strategies to close resource loops. Combining PSS with reverse logistics chain and the remanufacturing process can result in a close loop of products. However, for the construction industry, the long-term operating life of buildings is a challenge as it may take decades to validate if today’s circular ideas have translated into circular results. PSS creates a business culture that enables closing resource loops, but they do not always result in fully closed and circular systems if the products are finally wasted or downcycled due to the absence of financially viable regenerative alternatives (Azcarate-Aguerre, Andaloro, et al., 2022).

3 Narrowing resource loops or resource efficiency focus on reducing resource use per product (e.g., design optimization of a building structure for the amount of steel required). It is already being implemented in linear economic systems and has limited influence on resource circularity as it focuses on decreasing the volume instead of creating regenerative flows (Azcarate-Aguerre, Andaloro, et al., 2022; Bocken et al., 2016). However, it can be combined with the other two strategies to develop circular systems (Bocken et al., 2016).

Therefore, PSS can be assessed based on the following CE principles to determine their inherent level of circularity (Bocken et al., 2016).

- a. The product’s ability to slow loops:
The product is designed for extensive lifespan (durable) and life extension (via methods such as maintenance and repair).
- b. The product’s ability to close loops:
The product is designed for disassembly and technological or biological cycles – allowing materials and components to be easily used in the future.
- c. The BM’s ability to slow loops is to exploit residual value to maximize usage and reduce cost.
- d. The BM’s ability to close loops is the creation of new processes to use residual outputs (e.g., waste of one process is new circular input for another process).

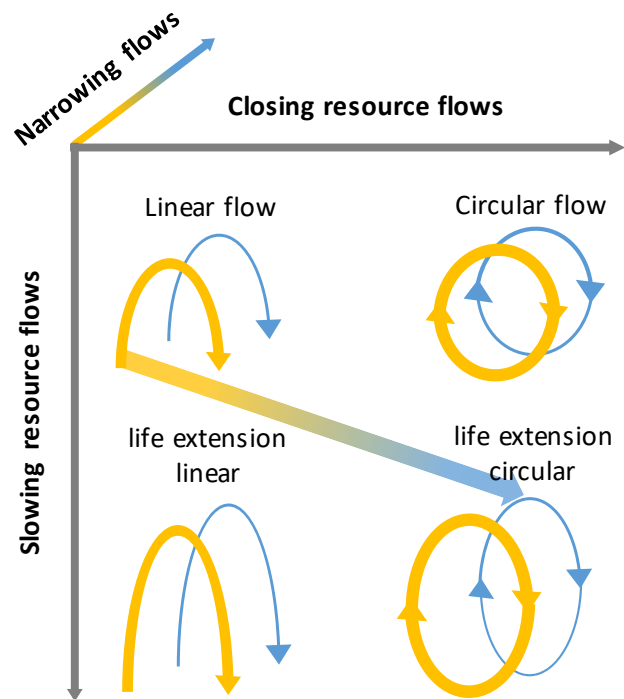


Figure 14: Categorization of linear and circular approaches for reducing resource use; adapted from Bocken et al. (2016).

Table 8: Design strategies for circular products and BM; adapted from Azcarate-Aguerre, Andaloro, et al. (2022).

| Approach | Product design strategies | | Business model strategies |
|---------------|--|---|---|
| Slowing loops | Design long-life products | <ul style="list-style-type: none"> • Design for attachment and trust • Design for reliability and durability | <ul style="list-style-type: none"> • Access and performance model • Extending product value • Classic long life • Encourage sufficiency |
| | Design for product-life extension | <ul style="list-style-type: none"> • Design for ease of maintenance and repair • Design for upgradability and adaptability • Design for standardization and compatibility • Design for dis-and reassembly | |
| Closing loops | <ul style="list-style-type: none"> • Design for a technological cycle • Design for a biological cycle • Design for dis-and reassembly | | <ul style="list-style-type: none"> • Extending resource value • Industrial symbiosis |

3.5 Sustainability Potentials of PSS

PSS has grown in popularity as a means of attaining sustainability (Inagaki et al., 2022). They are integrated solutions of products and services that can sustainably meet end users' needs, “ensuring that our actions do not limit the range of economic, social, and environmental options open to future generations” (Hernandez, 2019). The concept is valuable, yet it is not a panacea as it cannot address all sustainability issues (Ceschin, 2014). Initially, PSS was considered a more sustainable alternative to traditional product sales; however, it has been acknowledged that sustainability is not intrinsic to PSS (Barquet et al., 2016; de Jesus Pacheco et al., 2019; Doualle et al., 2015).

PSS can help promote sustainability in several ways. It can decrease the negative environmental consequences of production and consumption by offering services rather than products (Kuo et al., 2010). For instance, a car-sharing company can minimize the number of vehicles produced and the industry's environmental impact. Moreover, the shift to service delivery assures the development and production of sustainable products (Kuo et al., 2010), resulting in more durable, reusable, or easier-to-repair products.

The functional economy that lies at the core of the PSS concept offers an appropriate strategy for reshaping the current structure of production and consumption toward a more dematerialized one. Likewise, efficient resource utilization and dematerialization are crucial for incorporating environmental and social issues into the company's strategic objectives and processes while enhancing competitive advantage. PSS can result in fewer material flows and emissions than product-oriented models; however, they can also have negative environmental consequences while providing economic benefits (Barquet et al., 2016).

It is essential to emphasize that PSSs do not guarantee sustainability; they have the potential to do so if properly designed, developed, and delivered (Ceschin, 2014; Vezzoli et al., 2015). Yet, even well-designed, some PSS could have undesired side effects, referred to as rebound effects (Vezzoli et al., 2017). Since societal systems are complex and interrelated, at a practical level, they result in unforeseen circumstances and can lead to an unintended increase in the consumption of environmental resources despite the efforts to implement environmentally friendly solutions. An example would be the influence of PSS on consumers' behavior; leasing instead of ownership of products might result in careless behaviors (Vezzoli et al., 2015).

Numerous recent studies have concluded that the environmental performance of PSS can be worse in a specific situation than in product-oriented models (Barquet et al., 2016; de Jesus Pacheco et al., 2019; Kjaer et al., 2019). Such ambiguities and contradictions limit PSS BMs from providing potential sustainability benefits and may hinder their adoption (Barquet et al., 2016).

Hernandez (2019) adds that companies do not perceive genuine motivation to shift to PSS and do not see many examples of PSSs in the market achieving substantial benefits in terms of the triple bottom line of sustainability. Furthermore, it states that most studies and literature on the topic have been primarily theoretical, indicating that further empirical study is required. This absence of empirical proof is critical, particularly for small companies with little room to experiment with unproven ideas. Despite the rising number of academic articles on the topic, the research area is still young (Hernandez, 2019).

Tukker and Tischner (2006) argue that to conclude that PSS is synonymous with sustainability is a myth. Blüher et al. (2020) state that the reasoning that PSS is sustainable is often built upon the CE characteristic of PSS. The real strength of the PSS concept is that it differs from the product-oriented models and focuses on the final need or function, resulting in a high degree of freedom to look for sustainable solutions. When sustainability is considered in PSS design, untapped potentials for achieving sustainability may be revealed (Tukker & Tischner, 2006).

As a result, PSS should be designed, developed, and delivered specifically for eco-efficiency, establishing economic and competitive motives to optimize material and energy use while reducing environmental consequences (incorporating a closed-loop system) (Vezzoli et al., 2017). Thus, an eco-efficient PSS is defined as a PSS “*where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions*” (Vezzoli et al., 2017). An eco-efficient PSS combines the economic objectives of stakeholders with the desire to reduce resource consumption. Although eco-efficient PSS is not a sustainable PSS, it is a step in the right direction for achieving sustainability in the long run. The first addresses the economic and environmental dimensions, while the second also addresses the social and ethical dimensions (Ceschin, 2014). Vezzoli et al. (2015) define sustainable PSS as “*an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a ‘unit of satisfaction’), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally and socio-ethically beneficial new solutions*” (p. 2).

Sustainable PSSs are win-win solutions, providing advantages in terms of environmental, socio-ethical, and economic sustainability. Regrettably, because of the numerous challenges involved, the concept’s acceptance in practice is still limited (Hernandez, 2019), and examples of this BM in the market, particularly in Business-to-Customer (B2C) operations, are scarce. (Tukker, 2015; Vezzoli et al., 2015). Tukker and Tischner (2006) underline that concerning the low uptake of sustainable PSS from a company perspective, a shift to PSS, like any other business movement, must be analyzed and carefully managed since it is possible to lose competitive advantages and fail to realize the desired benefits.

3.5.1 Sustainability Factors of PSS

Barquet et al. (2016) represent the following five factors that make PSS a sustainability BM; Figure 15 illustrates the factors and sub-factor for PSS sustainability.

- 1- ***Factor 1: Design for Environment*** is intended to incorporate all phases of the product lifecycle by reducing emissions, reducing material and energy consumption (i.e., using low-impact materials, environmentally friendly materials, and energy-efficient technologies, cleaner technologies), using efficient distribution network and likewise considering disassembly, upgrading, and adaptability principles.
- 2- ***Factor 2: Identify economic value for each stakeholder*** entitles to reducing production and material consumption through product longevity, resulting in cost savings. This, in turn, encourages PSS lifecycle extension and profitability of new services.
- 3- ***Factor 3: Promote behavior change for customers and PSS providers*** by educating customers and PSS providers to overcome the high symbolic values associated with product ownership, increasing consumer and employee engagement and the satisfaction of the

consumer's needs. Transparency and a product's appearance, usability, price, and time and cost-saving features can represent this sustainability factor.

- 4- **Factor 4: Delineate actions to social well-being** as PSS should create new jobs, secure existing ones, improve working conditions, and promote fairness. It should strengthen local economies, foster social well-being, and broaden access to services by lowering costs. Furthermore, it should encourage social integration and increase the quality of life.
- 5- **Factor 5: Innovation at different levels** is required to ensure PSS's practicality and economic viability. Implementing new organizational, financial, legal, and social structures is crucial. Additionally, innovative product services and technology must be developed to support these arrangements. Furthermore, to create an integrated solution, technological and value chain innovation are required, as well as the convergence of stakeholders' interests to extend product life and use. Technological innovations can result in more environmentally friendly products and services, and this aspect can be addressed by strategies such as on-site assembly and remote control of products for maintenance and repair.



Figure 15: Sustainability factors and sub-factors for PSS; adapted from Barquet et al. (2016).

3.5.2 PSS Archetypes and Sustainability Potential

Tukker (2015) emphasizes the environmental impacts of different types of PSS when designing sustainable business strategies and concludes as follows. Product-oriented services may result in limited improvement of resource efficiency and, at best, create some environmental benefits because the providers are well off to sell more products and their parts and even have the incentive to create planned obsolescence to sell replacements. Use-oriented service appears to have mixed effects where leasing often results in careless behaviors, having a negative impact, and product sharing and renting; specifically pooling, may lead to significant benefits as the product is shared and used more intensively. Finally, result-oriented service, in theory, has the highest potential for environmental benefits since they focus on creating completely different solutions from the existing product concepts, and using materials become a cost factor. According to the author, these services' effectiveness depends on the practices implemented, and specific outsourcing strategies may not result in considerable efficiency benefits (Tukker, 2015).

Yang and Evans (2019) compare four PSS types (product-oriented, integration-oriented, use-oriented, and result-oriented) and conclude that all PSS archetypes result in a certain level of enhancement in sustainability performance. The study shows that different PSS archetypes impact sustainable value creation to varying extents, as shown in Figure 16. Furthermore, the study affirms that the greater the focus of a PSS on achieving results, the higher the potential for sustainable benefits, which is consistent with the finds of other studies (Tukker, 2015; Tukker & Tischner, 2006).

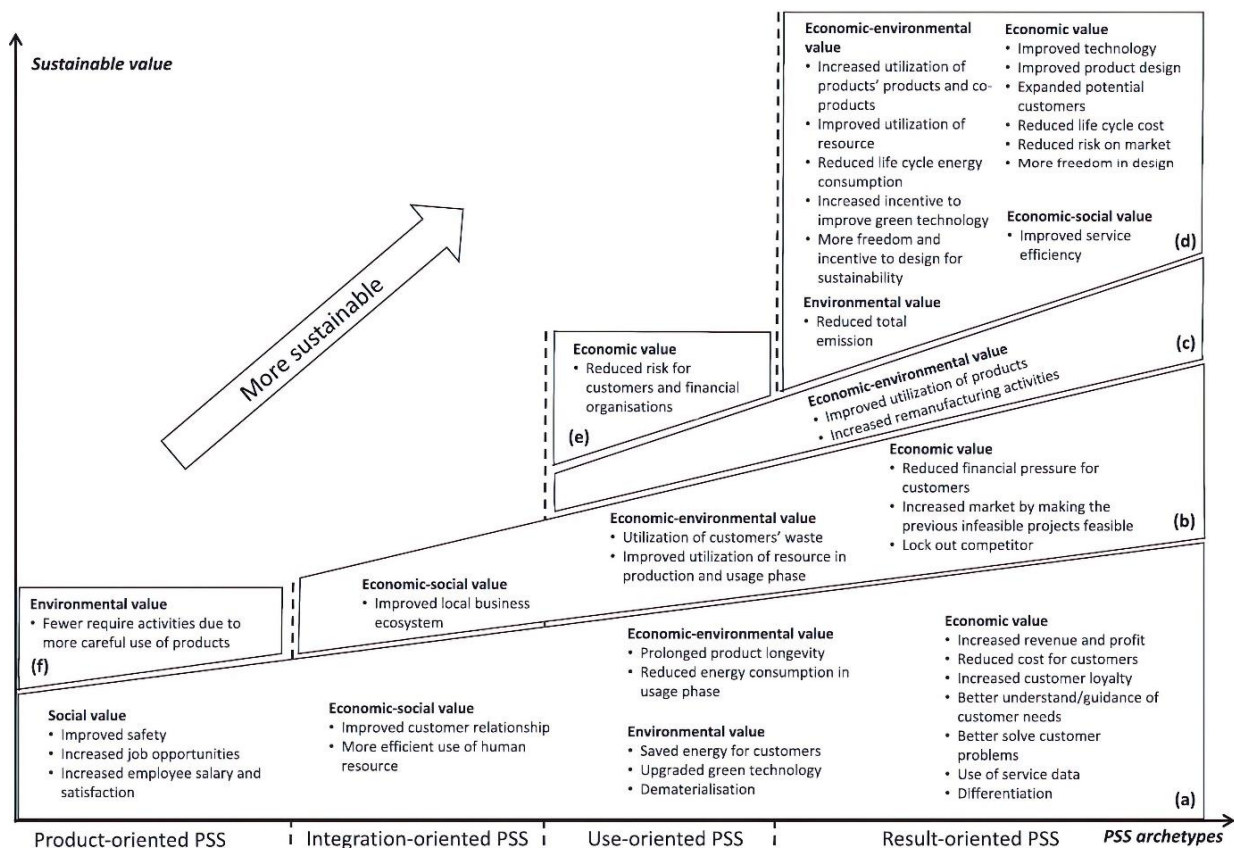


Figure 16: PSS archetypes and sustainability potential; adapted from Yang and Evans (2019).

In Figure 16, the portion (a) outlines the shared sustainable values in the four types of PSS. The area of the box indicates that these values rise as a PSS move toward result-oriented. For instance, all types have the economic value of increasing revenue; however, this value becomes more significant as a PSS becomes result-oriented. This suggests that result-oriented PSS outperforms other archetypes in these shared sustainable values. Portion (b) represent sustainable values shared in three PSS types: integration-oriented, use-oriented, and result-oriented, excluding product-oriented. For instance, the economic-environmental value “utilization of customers’ wastes” is shared in the other three types but not in product-oriented. Thus, the implementation of these sustainability values depends on the context. Overall, the more result-oriented a PSS, the stronger these features are. Portion (c) shows common values in two types of PSS use-oriented and result-oriented. Portion (d) describes sustainable values unique to result-oriented PSS, such as more freedom and incentive to design for sustainability and minimize the total emissions. Portion (e) reflects the sustainable value creation unique to use-oriented PSS. Lastly, portion (f) shows the sustainable value specific to product-oriented PSS. In this model, the customer owns the product, which means that customers are inclined to use products more carefully to last longer (Yang & Evans, 2019).

Yang and Evans (2019) progressed on to evaluate the main reasons contributing to differences in sustainable value created in each type, based on empirical data, and it determined that the differences are significantly associated with the degree of integration among the product maker, owner, and user. As illustrated in Figure 17, the more integrated the maker, owner, and user are, the stronger the sustainable feature becomes. Tukker (2015) has also briefly stated that the ownership argument could be considered a valuable quality, emphasizing that product ownership provides a sense of control and enables more freedom while using the products.

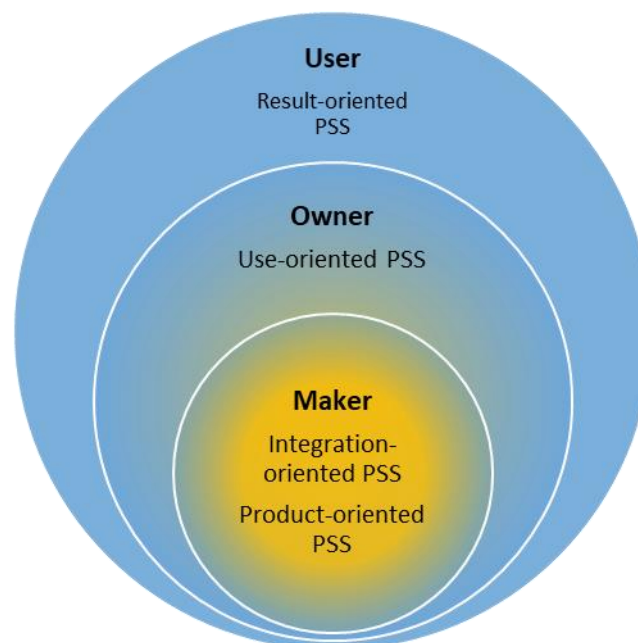


Figure 17: Product maker, owner, and user integration in PSS archetypes; adapted from Yang and Evans (2019).

3.6 Potential Benefits of PSS

Ceschin (2014) argue that there are several benefits of PSS and group them into three main categories: economic and competitive, environmental, and socio-ethical benefits, which are further explained in the following paragraphs.

PSS increase competitive advantage by representing different offer (customizable to the client and low-cost economies), adding value to customers (not responsible for acquisition, use, maintenance, and disposal), and promoting longer and stronger relationships with customers (the resulting in feedback collection, better value propositions, and customer loyalty), being difficult to copy, and helping comply with environmental legislation (such as extended product responsibility, environmental performance, standards, and specific international agreements) (Ceschin, 2014).

Environmental benefits of PSS are associated with the fact that stakeholders included in the PSS offer have an economic and competitive interest in optimizing material and energy consumption, which also encourages the actors to enhance environmental performance. The confluence of environmental and economic interest is defined as eco-efficiency. PSS providers are economically interested in the following environmental benefits of an eco-efficient PSS: extended product life, intensified use of the product and its components, extended reuse of materials, minimized resource use, use of more advanced technologies, substitute obsolete product with efficient ones, and implement sufficiency solutions (Ceschin, 2014).

The socio-ethical benefits are grouped into two main clusters: socio-ethical benefits for customers (Improved quality of life and significant opportunity for contexts with fewer economic possibilities, low-income) and socio-ethical benefits for society as a whole (increase in local employment, disseminating of competence, new business opportunities for companies, strengthen the role of the local economy, and regenerating and empowering local economics) (Ceschin, 2014).

Most scholars agree on the key benefits of PSS listed in the study by Annarelli et al. (2016). The benefits are locking out competitors, locking in customers, differentiation, image improvement, new market development, reducing environmental impact, consumption efficiency, cost reduction, revenue increase, customer engagement, and legitimacy of servitization. The majority of these PSS benefits are internal benefits, and according to the author, the most cited PSS benefit in the literature is “reduce environmental impact, and the most cited internal PSS benefit in the literature is “differentiation against competitors” as services-oriented businesses are more difficult to replicate (Annarelli et al., 2016).

In a review study, Beuren et al. (2013) classify PSS benefits into four categories: customer, provider, environment, and society. The study focuses on external PSS benefits and emphasizes PSS benefits for customers. Based on the study, the most often stated PSS benefit was “disconnection from the responsibilities of ownership,” also highlighted by (Tukker, 2015).

Moro et al. (2020) conducted an overview of the literature on PSS benefits and identified the two categories: internal and external, which are further sub-categories into the design, economic, customer, and context-based (environmental and social) benefits, summarized in Table 9.

According to (Moro et al., 2020), numerous publications highlight the benefits of PSS considering the internal side of the companies, particularly the economic side, and no benefits that fall into the operation category were identified. The author speculates that this might be due to the lack of longitudinal studies on PSS. The highlighted environmental benefits may favor providers and society (Annarelli et al., 2016; Moro et al., 2020). On the other hand, Moro et al. (2020) concluded that social benefits are rarely addressed in PSS research.

Table 9: The main benefits of PSS; adapted from Moro et al. (2020).

| Internal Benefits (16) | | External benefits (20) | | |
|--|---|--|--|--|
| Design (3) | Economic (13) | Customers (6) | Context-Based (14) | |
| | | | Environmental (9) | Social (5) |
| <ul style="list-style-type: none"> • Ease of collecting product use information • Greater contact with the customer • Differentiation against competitors | <ul style="list-style-type: none"> • Increase in profit margin • Image enhancement • Reduction of costs (energy & materials) • Efficient use of equipment • Increase in value-added • Increase customer satisfaction • Creating clients' and providers' dependency • Improve position in the value chain • Constant cash flow • Elimination of seasonality • Value delivery through the lifecycle • Development of new market • Customer loyalty | <ul style="list-style-type: none"> • Disconnect from ownership responsibilities • Reduction of costs • Disconnect from consumption needs • Offers professional maintenance • Reduced efforts for product operation • More customized solutions | <ul style="list-style-type: none"> • Greater use of products • Reducing environmental impact • Efficiency of consumption • Closing lifecycle • Waste reduction • Reduce resource use • Facilitate reuse and recycling • Dematerialization • More durable products | <ul style="list-style-type: none"> • Job creation • Facilitate reverse logistics • Use more advanced and efficient technologies • Improve the well-being of society • Provide access to more people |

3.7 Challenges in Adopting PSS

PSS is frequently discussed as a means to improve the sustainability performance of conventional production systems. This is due to their ability to improve resource efficiency by extending the lifespan of products and separating value from the mere provisioning of tangible products. However, they do not guarantee resource reduction, let alone absolute resource decoupling. Product leasing, for example, is not necessarily more environmentally friendly. Yet, it may encourage more frequent product replacement. PSS could lead to more people accessing the product, eventually increasing consumption instead of decreasing it. Takeback services may include product redistribution and reusing. But still, used items do not necessarily replace new products; if sold at a lower price, they may result in rising total consumption. From a business standpoint, this is advantageous because it prevents cannibalization but does not lead to net resource savings. Furthermore, rebound effects concerning PSS are yet another well-known issue (Kjaer et al., 2019). Since a PSS often changes user behavior, it can undermine the potential for resource reduction (Goedkoop et al., 1999).

Regarding implementation, although the concept of PSS has been explored in the literature for decades, its practical application is limited because shifting a business to PSS necessitates changes in internal corporate technology and maintenance, service, and supply chain management upstream and downstream (Kuo et al., 2010).

Hidalgo-Carvajal et al. (2021) identify three main hard challenges for companies transitioning to serviced BM: technical, economic, and market. Each has its subcategories; for example, technical challenges, including BM design, capabilities for servitization, and technology management. The economic challenges include financial management and changes in cost structures, while market challenges include supply chain management and market readiness. Moreover, the paper discusses soft challenges related to the shift from selling products to delivering services into three categories: regulations, institutional/managerial issues, and social/cultural issues. Regulations include internal policies and external regulations, while institutional/managerial issues include a lack of readiness for servitization and organizational rigidity. Social/cultural factors, internal and external, include the cultural paradigm shift required to transition from owning products to receiving services and developing new customer relationships.

There are also some risks associated with PSS; Kuo et al. (2010) summaries them as follows: fewer products sold, new responsibilities, cross-industry collaboration may go further to embrace materials pooling, financial risk (need for pre-investment), challenging market conditions, no legislative pressure, no prior characteristics, fashion vulnerability, and resistance to change from both producer and customer.

In addition, many small and medium-sized companies do not have the resources that large companies have (Åkesson et al., 2022). Therefore, they face many challenges in shifting to PSS. One of their most common challenges is a lack of financial support besides the requirement of the new organization, new customer relationships, new contracts, and new economic models. Furthermore, there are many challenges, such as a lack of knowledge and competencies related to sustainability and PSS design due to the complexity of existing design methods, regulations, and administrative processes. Creating PSS necessitates fundamental changes in the strategy and structure of companies (Åkesson et al., 2022). A summary of the main challenges for small and medium-sized companies transitioning to PSS is presented in Table 10.

Table 10: Main challenges for small and medium-sized companies in designing PSS; adapted from Åkesson et al. (2022).

| Internal challenges | External challenges |
|---|---|
| <ul style="list-style-type: none"> • Time constraints • Current business model • Financial resources • Organizational structure & internal processes • Dedicated employees for service development • Competence | <ul style="list-style-type: none"> • Position in the value chain • Customer interest in PSS solutions • Handling of reversed logistics |

It is important to mention that there are various barriers to PSS that challenge its uptake, which is the topic of chapter four. Understanding these barriers is necessary for developing effective strategies to overcome them and promote the adoption of PSS. Addressing these challenges and barriers can accelerate the shift toward a more sustainable future discussed in chapter five.

3.8 PSS Implementation in the Building Sector

This section examines PSS implementation in the building sector using data from literature and practice.

3.8.1 PSS Implementation in Theory

A building is a complex system comprised of layers of interconnected subsystems (Keymer, 2000). Brand (1995) proposed a six-layered model: stuff, space plan, services, structure, skin, and site, as illustrated in Figure 18. In this model, each layer has a lifespan, must be changed at various rates (Brand, 1995), and serves a different function for building users (Keymer, 2000). Conceptualizing a building this way suggests that the layers should be modular and independent to enable ease of maintenance, upgrading, and re-use (Brand, 1995). This method, however, may limit the potential of a PSS. A well-integrated PSS, for example, may combine multiple layers of a building into one system for optimal performance. According to Van Ostaeyen et al. (2013), the building's thermal comfort delivery is optimized when a single PSS offering integrates the building's skin and systems (heat, cooling, and ventilation).

Keymer (2000) suggests viewing buildings as a group of functional systems that may or may not be physically separate. A window, for example, is a component of both the exterior enclosure and the internal finishing systems. A building's systems can interact via various mechanisms (Slaughter, 2001), and the nature of these interactions and the systems themselves impact the buildings' flexibility, durability, and sustainability in responding to multiple changes. It is essential to recognize the impact caused by system interaction while evaluating the construction, operations, and maintenance of a building because these influences can cause a cascade of secondary effects in construction complexity and cost. Each system can be evaluated as an independent entity as long as the implications of that system's relationships with other subsystems are identified and analyzed. One particular impact is the risk of progressive failure, which happens when the failure of one subsystem result in the failure of another. For example, if site-fixed panel partitions do not enable access, a modular wiring system may fail to provide flexibility (Keymer, 2000).

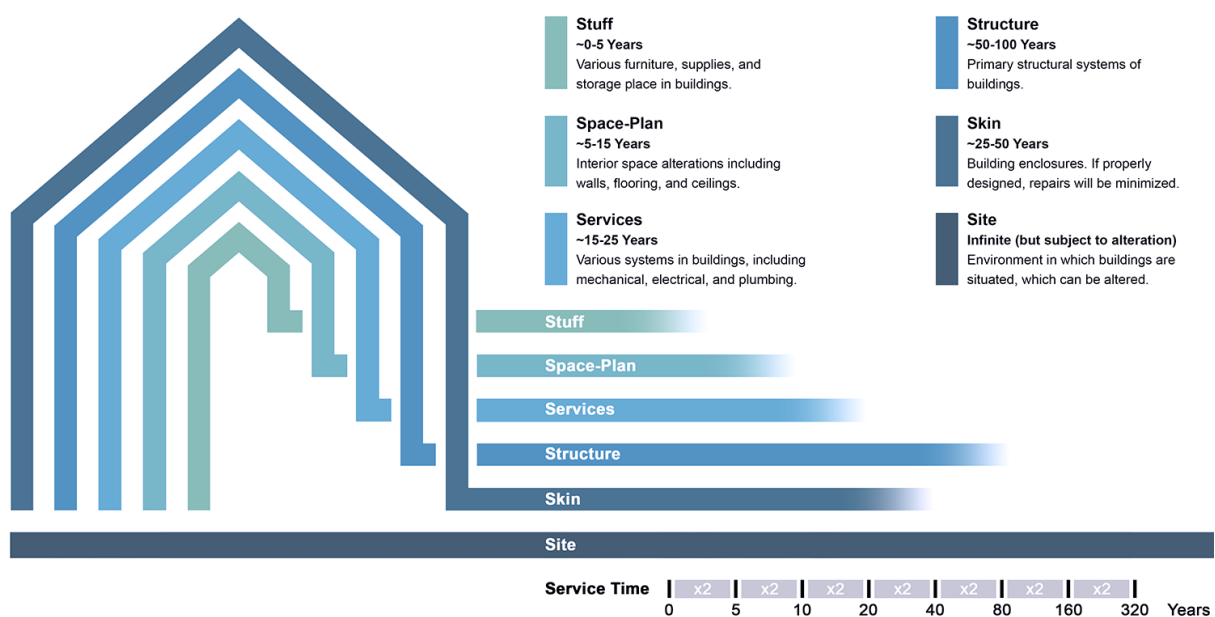


Figure 18: Six layers of a building and its lifespan; adapted from Overbey (2022).

Based on the six layers, the focus of PSS is on the following four layers: stuff (Chairs, desks, kitchen appliances, lamps, etc.), space plan (The Interior layout – walls, ceilings, floors, and doors), services (e.g., communications wiring, electrical wiring, plumbing, HVAC, and elevators), and skin (exterior surfaces, facade). While the structure of a building, including the foundation and load-bearing elements, is expensive to change, and the site, which is the urban location, lasts centuries. However, if the whole building is designed for de-and-reassembly or transportable, the sites and the user could easily be changed.

According to Tukker (2015), PSS BM are suitable for products that are typically expensive, complex in their technology, require regular maintenance and repair, are easily transportable, infrequently used by customers, and are not significantly affected by branding and fashion.

3.8.2 PSS Implementation in Practice: Interviews Findings

Based on the interviews, this sub-section discusses PSS implementation in practice and is divided into two parts. The first part examines what the companies offer, and the second deals with the applicability of PSS in the building sector.

PSS Offerings

Companies in the building sector offer a variety of PSS. One of the companies provided Facades-as-a-Service (FaaS). They started with product-service and are creating and developing data to understand how to take the next steps. They have only two projects offering PSS using service contracts and performance-based agreements. However, they plan to expand their product-service offerings (BP1). Other companies provide partition walls, glass walls, meeting spaces systems (BP3), door, window, ceiling, interior construction and absorlux acoustic systems (BP4), transparent glass walls (BP8), and Kitchen-as-a-Service (KaaS) (BP5). These companies produce and assemble reusable products to facilitate reuse and maximize product lifespan.

BP4 stated that they generally do not have integrated product-service contracts. They produce and assemble products such as doors and walls and typically have new arrangements for maintenance. However, occasionally, they have PSS where they disassemble and buyback. But now, they want to expand by introducing a lease contract. However, financing these products is a significant obstacle, as a bank would not invest in such BM (BP4).

BP5 mentioned they have many propositions of the PSS umbrella, providing circular and modular Kitchens to professional rental markets, temporary housing, companies renting out apartment blocks and houses to tenants, housing associations, and institutional investors. They are only working with larger-scale clients and not individuals; however, they are trying to enter this market. It is challenging due to credit checks on the clients and demand variations. The more standardized the products, the more they can be reused. They offer clients the option to buy the kitchen and rent the appliance, with a buy-back guarantee. Furthermore, they have mutual buy-back grantees and agreements for a specific price, incentivizing suppliers to design durable products and providing them with return and reuse information (BP5).

One of the interviewees mentioned that they offer maintenance and integrated contracts for buildings, but they do not provide performance yet. That is what they are aiming to do in the future. They are experimenting, but it is not their primary BM (BP6).

Another interviewee stated that they have two projects concerning PSS (BP8). One project focuses on transparent glass walls, which require minimal changes to the existing product, while the other explores the possibility of implementing PSS in the entire building scale, including the wood, facade, elevators, light-as-a-service, and climate-as-a-service. For example, with climate-as-a-service, companies must optimize the whole system, including the supply chain, installation, disassembly, reuse, and other relevant systems like façade and insulation (BP8).

Applicability of PSS

PSS works better for products with shorter lifespans (BP6). For example, a car's typical lifespan is five to ten years. Therefore, it is possible to grasp and manage the risk and see how the automobile sector and the general market are moving and growing and what risks a company could face if it provides mobility-as-a-service. On the other hand, buildings have long lifespans, with commercial buildings lasting over 50 years and houses lasting over 75 years. This period is much longer than a company's capacity to define risks. For example, if a company build and finance a large building and keep the ownership of the steel while selling the bearing capacity as a performance to retrieve the steel at the end of the building's life, it cannot convince banks or investors (BP6).

Besides, it is better to experiment with products that have value at the end of life. For example, one of the companies experimented with living-as-a-service (BP6). Instead of selling the house, they wanted to sell living performance, receiving a certain amount monthly. However, it turns out that it is not a good business case. The question was the company's benefits as they tolerated more risks in a challenging market, not selling many. A missing part was the collective value of the product and materials, which resulted in moving away from the BM. PSS works better for systems and elements that act more like a product, such as a kitchen, door, windows, inner walls, and carpets with short-term living. However, “a building is not a product but rather an interface between product and urban development. For example, if you see the structure of a high-rise building, it is part of the city and urban area, and it does not go away soon” (BP6). For the inner layers of a building, like steel, wood, and concrete structures, there could be a buy-back as the value of the materials would certainly be higher in the future (BP8). Moreover, from the circularity and sustainability perspective, a PSS is only good if the product and material have value at the end of their first life (BP6).

Take-back value, take-back or buy-back guarantee, and leasing are the starting point (BP6; BP8). Companies often focus on who will use their products (building) but do not focus on the supplier's side. If they are sure about the take-back and the residual value of products and materials, they can start thinking of PSS. In addition, the products should be standardized (BP5). A problem in the building sector is that each building is unique, especially in the commercial sector: every building is a prototype and a finished product simultaneously. Therefore, it is hard to translate the PSS concept to the whole building, particularly non-residential buildings. If we want to apply PSS in these buildings, it helps to approach them from the system layers perspective (six layers) (Brand, 1995) and focus on the short life layers of the building, space plan, services, and stuff (BP6). A challenge is to define the performance of a PSS to deliver for a specific part or subsystem of a building system (BP6). PSS is applicable if you can monitor the use; for example, the number of times a lift goes up and down (BP8).

However, PSS in the built environment is challenging because the legislation says that the owner owns it if it is part of the building. Putting a true PSS, like pay per performance, use, or month, in the building sectors is hard, and all legal issues must be overcome. This is one of the reasons that there are not a lot of PSS in the building construction sector or the built environment, but there are more in the consumer market or product groups that are easily transferred (BP5).

In addition, PSS providers should influence the product's design in one way or another. They should design their product or have an excellent spin-off of the original design, which is essential if they do not affect the product's design. They cannot change the product to help circularity and sustainability (BP5).

Furthermore, currently, there are only financial incentives to reuse. If there is environmental accounting in the future, which could happen soon, it will accelerate the shift to CE and concepts such as PSS (BP8). Moreover, materials are getting scarce, and in the future, using the existing material and products is the way to go forward, for which you already have the guarantee as the materials end up in your loop (BP5). As mentioned by BP5, these products and materials are around 70% cheaper than virgin materials.

Most clients who think PSS solutions are interesting are government institutions or some companies that are really into sustainability, whereas smaller companies and individual users are not yet interested. However, companies do not offer products and services to individual clients. They focus on offices and schools as their products are fit and specialized for these clients; for example, no one will pay for sound-insulated ceilings in their house (BP4). The companies focus on professional rental markets, temporary housing, housing associations, and institutional investors (BP1; BP3; BP4; BP5; BP6).

Based on the interviews conducted for this study, most companies in the building sector are currently experimenting with PSS. Seven out of eight companies were providing or experimenting with PSS, while one company opted out due to negative experiences with integrated contracts (BP2). These services primarily target Business-to-Business (B2B) relationships and clients like social housing rather than individuals. The focus of most PSS offerings is on maintenance and buy-back guarantees, which serve as the initial step towards performance-based PSS. Some companies rely on whether their customers desire to disassemble and resell their acquired products. If customers wish, the companies will repurchase the products and offer them to environmentally concerned customers looking to lessen their environmental impact.

Chapter 4 **Barriers to PSS**

This chapter provides a comprehensive analysis of the barriers to PSS for contractor companies, aiming to thoroughly understand the challenges companies face in adopting PSS. Section 4.1 identifies these barriers through a review of literature and interviews and categorizes them. Section 4.2 presents a list of identified barriers analyzed based on the number of times cited by studies and interviews, providing a quantitative analysis. This section also highlights the barriers companies could overcome to help specify the focus of the next chapter, identifying solutions to overcome these barriers.

4.1 PSS Barriers

Despite the potential benefits, adoption of PSS is still limited (Hernandez, 2019; Vezzoli et al., 2015) due to the various barriers that companies face (Hannon et al., 2015), such as high upfront investments, design challenges to create durable products, lack of resources, and product ownership. The interplay of the barriers hinders the transition to PSS (Vezzoli et al., 2015). It is essential to mention that in the context of this study, anything that blocks or impedes the implementation or progress is a barrier. For example, companies may lack investment capital or face different customer behaviors. The following subsections present barriers identified from the literature review and interviews.

4.1.1 Barriers from Literature

This part presents the barriers to PSS for providers identified using the systematic literature review method explained in section 2.1.1 of chapter two. This sub-section discusses the 41 barriers identified, which are categorized into ten categories, a summary of which is presented in Table 11. The citations in this table are based on Table 4, which represented studies included in the literature review to ensure clarity and save space.

Table 11: Overview of the barriers identified from the literature review; the citations are based on Table 4.

| PSS barriers for companies from the literature | | | |
|---|-----------------------|---|--|
| # | Categories | Specific barrier | Citation |
| 1 | Customers | Long-term relationship/contracts | 1, 3, 12, 18, 23 |
| | | Lack of consumers interest | 4, 12, 15, 20, 25, 32, 33, 36, 41, 45 |
| | | Reduced care for products | 3, 13 |
| 2 | Supply Chain | Lack of standardization | 7, 44 |
| | | Lack of partners | 1, 4, 13, 25, 35 |
| | | Lack of information exchange between supply chain actors | 1, 4 |
| | | Lack of trust and collaboration in the supply chain | 3, 4, 10, 12, 18, 20, 21, 23, 25, 31, 36 |
| | | Stakeholders resistance | 4, 13, 45 |
| 3 | Organizational | Organizational complexity or administrative burden & responsibility | 1, 4, 10, 15, 20, 21, 24, 36, 37 |

| | | | |
|----|----------------------|---|--|
| | | Conflicts between business functions | 10, 12, 20, 24 |
| | | Change in organization processes and mindset | 1, 3, 10, 13, 15, 20, 33, 35, 45 |
| | | Reverse logistics | 4, 13, 15, 25, 36 |
| | | Lack of organizational commitment | 10, 12, 13, 15, 20, 25, 37 |
| | | Lack of business strategy | 1, 12, 15, 20, 21, 25 |
| 4 | Resources | Lack of abilities and competencies | 1, 3, 7, 10, 12, 13, 19, 20, 21, 23, 25, 31, 33, 35 |
| | | Lack of human resource | 1, 3, 10, 12, 15, 20, 25, 44, 45 |
| | | Lack of financial resources | 1, 4, 10, 12, 20, 21, 25, 44 |
| | | Lack of information/data | 1, 4, 13, 18, 44 |
| 5 | Knowledge | Lack of knowledge and understanding | 1, 3, 4, 9, 10, 12, 13, 15, 18, 19, 20, 21, 27, 36, 37, 41, 44, 45 |
| | | Inability to quantify economic and environmental savings of PSS | 3, 13, 18 |
| | | Inability to deliver high-quality products | 4, 12, 18, 19, 21, 23, 25, 36, |
| | | Lack of sustainability awareness | 1, 12, 21, 25 |
| 6 | Financial | Profitability of existing business models | 9, 25, 36, 45 |
| | | Financial risk due to the long service life of buildings | 10, 12, 20, 21, 23, 24, 25, 31, 36, 45 |
| | | Profit calculation | 1, 9, 10, 13, 20, 21, 35, 37 |
| | | R&D investment in system and service integration | 1, 3, 10, 31, 37 |
| | | High upfront costs and lower upfront profits | 1, 3, 4, 9, 10, 12, 13, 18, 27, 31, 33, 36, 37, 45 |
| 7 | Technology | Design challenges to create durable products | 4, 12, 45 |
| | | Lack of digitally-enabled services and technological readiness | 7, 24, 27 |
| | | Lack of an effective information management system | 13, 24, 15 |
| | | Lack of external infrastructure and technologies | 1, 3, 18, 33 |
| 8 | Regulation or policy | Change in ownership of physical elements in the system | 21, 25, 45 |
| | | Lack of supportive rules and regulations | 1, 3, 4, 9, 15, 23, 24, 35, 36, 37 |
| | | Lack of methods and specific guidelines for the transition | 1, 12, 25 |
| | | Lack of sufficient governmental interventions | 3, 18, 20, |
| 9 | Environmental | Rebound effect | 13, 19, 45 |
| | | Environmental benefits are not always significant | 33 |
| 10 | Social | Differences in large consumer groups | 19, 44 |
| | | Resistance to established local habits and behavior change | 13, 19 |
| | | Resistance to adopt PSS by companies as customers misuse | 20 |
| | | Cultural acceptance | 1, 3, 7, 9, 10, 12, 15, 20, 35 |

The following paragraphs elaborate on the barriers based on the order of Table 11 to ensure clarity. However, the order in which they are listed does not imply their importance.

The first category of PSS barriers for companies is related to customers. This study identified three main barriers related to the customers' domain. The first barrier is the *long-term relationships/contracts* (Ceschin, 2014; de Jesus Pacheco et al., 2019; Inagaki et al., 2022), which encompass liability concerns (Schoonover et al., 2021) and complicated customer purchase and service acceptance behavior (Petrulaityte et al., 2017). Another barrier is the *lack of customer interest* (Kuo et al., 2010; Kusumaningdyah et al., 2019), as changing the mindset from product ownership to use-centered (de Jesus Pacheco et al., 2019) and customer acceptance (Annarelli et al., 2016) is needed. The last barrier specified in this domain is

reduced (Ceschin, 2014) or *no care for products* by customers (Moro et al., 2020) when they do not own them.

The second category of barriers is the following five barriers linked to a company's supply chain. The first is the *lack of standardization* in the construction sector, as diversity hinders industrial process implementation (Galera-Zarco & Campos, 2021), and standardization is a prerequisite (Sarancic et al., 2022). Lack of standardization could also be related to regulation and policy category; however, companies could influence this barrier, at least with their products, supply chain, and network. The second barrier is the *lack of partners* (Åkesson et al., 2022; Inagaki et al., 2022; Moro et al., 2020); there is a greater need for collaborative networks of partners. Another barrier is the *lack of information exchange between supply chain actors* (Inagaki et al., 2022) or the lack of partner information (Kroon, 2020). The next barrier is the *lack of trust and collaboration in the supply chain* (de Jesus Pacheco et al., 2019; Labbate et al., 2021). Co-dependence leads to concerns about decreasing core competence and sharing confidential information regarding a company's internal process (Petruaityte et al., 2017). The development and delivery of PSS often need strong collaborations between the actors involved; however, conflicting interests between companies and actors in the supply chain (Ceschin, 2014; Kroon, 2020; Schoonover et al., 2021) and the distribution of responsibilities (Schoonover et al., 2021) often makes it challenging due to reduced control of core competencies and influence on the business decisions (Ceschin, 2014; Vezzoli et al., 2015). The last one in this group is the *resistance of stakeholders with a vested interest in the linear economy* (Kroon, 2020) (resistance to change by stakeholders (Moro et al., 2020) and stakeholder acceptance (Annarelli et al., 2016)), including customers, supply chain actors, and market participants.

The third category of barriers to PSS includes six main organizational barriers. The first barrier is *organization complexity* (Ceschin, 2013; Inagaki et al., 2022; Vezzoli et al., 2015), comprising an increase in administrative burden and responsibility (Inagaki et al., 2022), complex management and planning processes (Vezzoli et al., 2015), and performance monitoring (Azcarate-Aguerre, Klein, et al., 2022). This complexity is compounded by a load of maintenance services and the difficulty of managing components for maintenance services (Kuo et al., 2010). The design could also be viewed as an internal capability (Hernandez, 2019), leading to more control over the process but more responsibility, liability, and risk for the company (Linder & Williander, 2017). The second one is the *conflict between business functions*, such as sales and services (Azcarate-Aguerre, Klein, et al., 2022; de Jesus Pacheco et al., 2019; Vezzoli et al., 2015), because of the absence of a common internal language and alignment of mindsets (Martinez et al., 2010; Vezzoli et al., 2015). The third barrier is the *change in the organization process and attitude* (Annarelli et al., 2016; Inagaki et al., 2022; Kusumaningdyah et al., 2019; Moro et al., 2020) containing the alignment of mindsets (Ceschin, 2014; Vezzoli et al., 2015) and capabilities (Ceschin, 2014) and low engagement in innovation activities (Labbate et al., 2021). This shift can be challenging due to the difficulty of controlling and managing materials, particularly the reverse logistics process. This leads to the next barrier, the *organization of reverse logistics* and challenges in performing and handling it (Åkesson et al., 2022; Moro et al., 2020) due to different recycling times, quantity, and quality of products (Kuo et al., 2010) and expertise and knowledge of products to restore them to the original or better condition (Linder & Williander, 2017). The fifth barrier in the set is the *lack of organizational commitment to PSS implementation* (Moro et al., 2020; Vezzoli et al., 2015)

and applying short-term management practice (de Jesus Pacheco et al., 2019) or lack of senior management vision, support, and commitments (Åkesson et al., 2022; Kuo et al., 2010). Waiting for others to succeed and only applying it when it is required. For example, companies will invest the minimum amount of resources in the transition to make them eligible to apply for projects if it is mandatory in the future; however, they will not devote themselves sufficiently. The last barrier of the category is the *lack of business strategy* (de Jesus Pacheco et al., 2019; Inagaki et al., 2022; Kuo et al., 2010; Sarancic et al., 2022) for integrating products and services and replacing the value of exchange with the value of in-use, needing long-term relations (Åkesson et al., 2022; de Jesus Pacheco et al., 2019). There is also a substantial ignorance of the significance of having a well-defined business strategy and its relationship with the opportunities to shift (Hernandez, 2019). Moreover, companies face difficulty defining the strategy (Åkesson et al., 2022) and *combining environmental and social aspects with economic aspects in business* (Labbate et al., 2021). There is a lack of knowledge and understanding about the connection between sustainability and services, including difficulties in defining the offerings and setting performance indicators. There is no common understanding of sustainability, let alone how services influence it (Sarancic et al., 2022).

The fourth category of the barriers specified by this study is linked to a company's resources, subdivided into four main barriers. The first barrier in this group is the *lack of abilities and competencies* (Ceschin, 2014; Galera-Zarco & Campos, 2021; Inagaki et al., 2022; Vezzoli et al., 2015) designing services (Kusumaningdyah et al., 2019; Moro et al., 2020), service-oriented offerings (as most of the companies only have experience with product offerings) (Hernandez, 2019; Kusumaningdyah et al., 2019), business management (Labbate et al., 2021), or leading positions (de Jesus Pacheco et al., 2019). Furthermore, the development of new processes such as reverse logistics, contract management, and subscriptions (selling services instead of products) (Van Opstal & Smeets, 2022) is also challenging requiring staff and training (Aguerre et al., 2018). The second one is the *lack of human resources* (Ceschin, 2014; Inagaki et al., 2022; Sarancic et al., 2022; Vezzoli et al., 2015), which includes leaders to pull the transition (de Jesus Pacheco et al., 2019) and qualified (Labbate et al., 2021) and technical personnel and support (Annarelli et al., 2016; Kuo et al., 2010). Companies only focus on what they must do since time and other resources are limited; however, it is essential to dedicate resources to look outside for possibilities and opportunities rather than focusing just on internal activities (Åkesson et al., 2022). The third barrier in this group is the *lack of financial resources* (de Jesus Pacheco et al., 2019; Sarancic et al., 2022; Vezzoli et al., 2015). The last barrier is the *lack of information/data* (Inagaki et al., 2022; Moro et al., 2020; Sarancic et al., 2022) to define customers' service acceptance behavior and design PSS for a specific context, culture, and need (Petrolaityte et al., 2017).

The fifth and one of the most cited categories of PSS barriers recognized in the literature review is associated with knowledge, sub-categorized into four. *Lack of knowledge and understanding* (Ceschin, 2014; de Jesus Pacheco et al., 2019; Inagaki et al., 2022; Vezzoli et al., 2015) is the first barrier in this group that comprises the know-how and expertise (Annarelli et al., 2016; Moro et al., 2020), awareness related to PSS (Clegg et al., 2017; Kuo et al., 2010; Linder & Williander, 2017), and technical information and knowledge for implementation (Ceschin, 2013; Labbate et al., 2021; Sarancic et al., 2022). Moreover, companies are unfamiliar with the PSS concept and the consequences of having one in terms of the environmental, social, and economic benefits they may obtain (Hernandez, 2019). The second one is the *inability to*

quantify PSS's economic and environmental savings (Ceschin, 2014; Moro et al., 2020). The third one is the *inability to deliver high-quality products* (Kroon, 2020) due to a lack of design competencies (de Jesus Pacheco et al., 2019; Linder & Williander, 2017) and difficulties in using the available tools to support the PSS design (Åkesson et al., 2022; Hernandez, 2019) that are conducive to repair, refurbishment, and reproduction (Schoonover et al., 2021). The last one is the *lack of sustainability awareness* (de Jesus Pacheco et al., 2019; Inagaki et al., 2022), limited knowledge and understanding of social and environmental issues (de Jesus Pacheco et al., 2019), and competencies related to sustainability (Åkesson et al., 2022).

The sixth and the most cited category of PSS barriers identified were financial barriers. The first barrier in this group is the *profitability of existing BMs* (Hannon et al., 2015; Linder & Williander, 2017); for example, some companies are financially successful in their current form and are thus hesitant to change their existing, product-based BM (Hannon et al., 2015). Besides, there is a lack of profitability/market to PSS (Annarelli et al., 2016), at least in the short term. The second one is *the risk perception of having to engage in costly implementations due to the long service life of buildings* (Annarelli et al., 2016), as cash flows and financial risks from payments are spread over time (Schoonover et al., 2021). These investment models are sensitive to global market trends (Aguerre et al., 2018) and macroeconomics, resulting in the financial vulnerability of PSS (de Jesus Pacheco et al., 2019) and negative perception due to the uncertainties (Labbate et al., 2021). In contrast, companies perceive existing BMs as financially less risky (Vezzoli et al., 2015). *Profit calculation* (Inagaki et al., 2022; Moro et al., 2020) is the third financial barrier. Companies often struggle to quantify PSS's economic and environmental savings/benefits (Ceschin, 2013; Vezzoli et al., 2015) for marketing the innovation to stakeholders or strategic partners (Vezzoli et al., 2015). In addition, they face difficulty in evaluating how to charge for solutions (Moro et al., 2020; Sarancic et al., 2022), establishing performance indicators (Labbate et al., 2021), and understanding the costing and pricing structures (Hernandez, 2019; Santamaria et al., 2016). Another barrier is *R&D investment in system and service integration* (Aguerre et al., 2018). For example, companies are required to change the income and payment method (Ceschin, 2014; Inagaki et al., 2022; Vezzoli et al., 2015) or system and sources of gaining profits (Ceschin, 2013, 2014; Vezzoli et al., 2015). Last but not least, *high upfront costs* (de Jesus Pacheco et al., 2019; Kusumaningdyah et al., 2019; Moro et al., 2020) and *lower upfront profit* (Ceschin, 2014; Clegg et al., 2017; Inagaki et al., 2022) are barriers due to a lack of financial investment capital to cover the high upfront cost (Annarelli et al., 2016; Vezzoli et al., 2015) to implement and run PSS BM (Petrulaityte et al., 2017). These models transfer financial risk to companies as capital is tied up (Annarelli et al., 2016; Ceschin, 2013; Linder & Williander, 2017).

The seventh barrier category is tied to technology, including the: *design challenges to build durable products* (Annarelli et al., 2016; de Jesus Pacheco et al., 2019), *lack of digitally-enabled services* (Galera-Zarco & Campos, 2021) and *technological readiness* (Azcarate-Aguerre, Klein, et al., 2022), *ineffective information management system* (Moro et al., 2020), and the *lack of external infrastructure and technologies* (Ceschin, 2014; Inagaki et al., 2022; Kusumaningdyah et al., 2019) for collecting, reusing, and recycling products and material (Inagaki et al., 2022; Petrulaityte et al., 2017).

The eighth category of PSS barriers relates to regulation and policy and is subcategorized into the following four. The first barrier is the *change in ownership of physical elements in the system* (Åkesson et al., 2022; Hernandez, 2019) and the legitimacy of servitization (Annarelli

et al., 2016). The other is the *lack of supportive rules and regulations* (Hannon et al., 2015; Kuo et al., 2010). Often, government policy fails to restrain environmental impacts and reward sustainable business activities (Linder & Williander, 2017). The next barrier is the *lack of methods and specific guidelines for orienting the transition* (de Jesus Pacheco et al., 2019; Inagaki et al., 2022). The last one is the *lack of sufficient governmental interventions* to encourage environmentally aware business development and practices (Labbate et al., 2021; Petrulaityte et al., 2017), as governmental institutions also face difficulties creating regulatory drivers to support and promote the adoption of innovations such as PSS (Ceschin, 2013, 2014).

The ninth category of PSS barriers in the literature related to the two succeeding environmental aspects: *rebound effect* (Gustafsson et al., 2021; Moro et al., 2020) and *environmental benefits are not always significant* (Kusumaningdyah et al., 2019). For example, PSS approaches may result in rebound effects that jeopardize the environmental impact (Gustafsson et al., 2021). Shared and leased consumption models may lead to unsustainable product and asset use, resulting in environmental damage instead of benefits (Annarelli et al., 2016).

The last category of barriers to PSS adoption for companies, as recognized in existing literature, pertains to social barriers. The first barrier is the differences in large consumer groups (Gustafsson et al., 2021), which result in difficulties in understanding customers' needs and accurately predicting customers' usage (Sarancic et al., 2022). The second barrier is resistance to established local habits (Moro et al., 2020) and behavior (Gustafsson et al., 2021). Furthermore, companies' resistance to adopting PSS is another barrier, as customers may misuse the product (Labbate et al., 2021), compromising financial planning. Lastly, *cultural acceptance* (Moro et al., 2020) is also an internal barrier and includes resistance to corporate change (Ceschin, 2014; de Jesus Pacheco et al., 2019; Inagaki et al., 2022; Kuo et al., 2010) and resistance to shifting to a PSS BM (Galera-Zarco & Campos, 2021) that requires organizational inertia. These models necessitate radical cultural and corporate reforms in product-oriented companies (Hannon et al., 2015). Due to past negative experiences, skepticism about new initiatives arises, resulting in low engagement in innovation activities and followers' mentality (de Jesus Pacheco et al., 2019). However, companies are required to support systemic innovation, such as PSS-oriented approaches (Vezzoli et al., 2015). Furthermore, there is a need for innovative behavior and cultural shift in the construction sector, as it remains far from industrial concepts like value chain or process orientation and lacks awareness of the significance of the supply chain (Galera-Zarco & Campos, 2021).

4.1.2 Empirically Identified Barriers: Insights from Interviews

Table 12 below summarizes the twenty barriers of PSS identified via the semi-structured interviews, which are grouped into eight categories. The citation in the table and the subsequent text in this sub-section are based on Table 5, provided in section 2.1.2 of Chapter Two, which includes the anonymized list of the individuals interviewed, whereas the list of the interview questions used in this study is provided in Appendix II – Interview Protocol

Table 12: Summary of the barriers via form interviews.

| PSS Barriers for companies from interviews | | | |
|--|----------------------|---|--------------------|
| # | Categories | Specific barrier | Citation |
| 1 | Customers | Long-term relationship/contracts | BP1, BP2 |
| | | lack of consumers interest | BP5 |
| | | Not able to communicate one-on-one with clients | BP5 |
| 2 | Supply chain | Lack of standardization | BP1, BP2 |
| | | Lack of partners | BP7 |
| | | Lack of information exchange between supply chain actors | BP4 |
| | | lack of long-term perspective by suppliers | BP1 |
| | | Lack of trust and collaboration in the supply chain | BP4 |
| | | Stakeholders resistance | BP1, BP3 |
| | | Storing of products to reuse | BP4 |
| 3 | Organizational | Organizational complexity or administrative burden & responsibility | BP1, BP3, BP5 |
| | | The BM cannot be easily replicated in other areas | BP5 |
| 4 | Resources | Lack of abilities and competencies | BP7 |
| | | Lack of human resource | BP3, BP5 |
| | | Proportionality, companies size, and capability | BP2, BP7, BP8 |
| 5 | Financial | Financial risk due to the long service life of buildings | BP2, BP7 |
| | | High upfront costs and lower upfront profits | BP1, BP5 ,BP8, BP3 |
| 6 | Technology | Building materials are low-profile and low-tech | BP6 |
| 7 | Regulation or policy | Change in ownership of physical elements in the system | BP5 |
| 8 | Social | Cultural acceptance | BP8 |

One of the main barriers to PSS is *contracts/long-term relationships* (BP1; BP2), which are the promises or appointment a company make that are relevant today and in the future. Foreseeing all future events is challenging, making it difficult to set performances and appointments for the long term that are relevant now and decades into the future. Therefore, finding solutions for other challenges is possible, but legal appointments on agreements are the bottleneck and pose significant challenges (BP1).

Suppliers' lack of a long-term perspective (BP1) is also a barrier since they deliver parts of the system or element without maintenance contacts. The service-provisioning company stays with the customers and handles maintenance; suppliers only deliver, but they should anticipate and welcome long-term partnerships. The challenge is to get suppliers enthusiastic about long-term relationships and encourage them to shift their perspective. It is crucial to find ways to trigger this change to overcome supply chain issues (BP1).

The *lack of collaboration and communication* is a barrier (BP4). The absence of cooperation and communication among disassembly and provisioning companies poses challenges to mining and reusing products. Some disassembly firms struggle to determine how to handle the products and where to sell them, whereas provisioning companies may know how to reuse products but have difficulty finding second-life products. “For example, despite having a large network of architects, clients, and companies, obtaining products and their parts for reuse remains difficult for us” (BP4). In addition, PSS companies lack sufficient personnel for one-

on-one communication with individual clients (BP5). Furthermore, what happens when someone sells their house? How can it be ensured that the new owner knows, for example, that the circular kitchen goes back to the company? (BP5).

The *administrative burden with PSS is significant* (BP1), requiring extensive paperwork and documentation. For example, buying agreements include long-term guarantees, but these guarantees can be voided if certain conditions are not met, resulting in increased responsibility and the need for meticulous document management (BP1). Companies have traditionally operated linearly, producing, assembling, and moving on. However, they must now adapt to produce once and assemble and disassemble multiple times (BP1; BP3), requiring additional management of products and documentation (BP1). Data management and documentation are complex and must be handled accurately (BP5).

Moreover, there is a *lack of skilled labor* as PSS requires more labor, which is expensive and highly taxed (BP5). It requires different skills and roles, considering product-oriented business, which has caused concerns about job security (BP3). “Some employees may be concerned about their jobs, but we value their skills in other areas, such as reassembling, disassembling, and sorting products to manage inventory and handle administrative tasks” (BP1).

With PSS, there are *many financial barriers*; for example, banks often require substantial financial guarantees, prompting discussions about the extent to which such guarantees should be provided (BP1). Leasing systems that involve product financing are challenging as banks are reluctant to finance such models (BP4, BP3). In addition, forecasting and mitigating financial risks associated with the long service life of a building is difficult (BP2; BP7). However, financing PSS internally is not always necessary and alternative models that do not require provider financing are also acceptable (BP1).

Pre-financing is a significant barrier to PSS adoption, particularly in B2C relations, where attracting capital and passing credit checks is more challenging than B2B relations (BP5). It is a critical barrier to most companies providing PSS solutions, even some companies experiencing zero account balances following a good month of sales due to significant pre-financing expenses. As a result, gaining new customers may be counterproductive for them (BP5).

Lack of short-term profit with PSS is another barrier in the financial category, as considerable investments are required, with returns expected in the long term (BP8). Moreover, articulating the value proposition of PSS to clients can be complicated, necessitating efforts to educate and persuade them of the benefits. As mentioned by (BP5), “We often have to preach instead of selling our solutions. Our clients sometimes do not understand what we are selling”. Although PSS is initially more expensive than traditional models, it is cost-effective and less costly in terms of the total cost of ownership in the long run. On the other hand, individual customers may lack a long-term perspective and may not fully grasp the benefits of PSS (BP5).

In addition, the *legal ownership of the product* in PSS is a barrier. As mentioned by (BP5), a kitchen is part of a house, and thus, the owner of the house is the owner of the kitchen. However, providing kitchen-as-a-service, “we want to maintain the ownership of the kitchen, but technically we are not.” Despite the provider retaining economic ownership, the legal ownership is held by the owner of the house, which can create issues when the owner defaults or refuses to pay. Consequently, the company cannot reclaim the kitchen from the tenant,

potentially disrupting the circularity loop (BP5). Navigating the complexities of legal challenges proves to be a formidable task. “Certainly, we can engage in collaborative lobbying efforts with fellow companies, but our ability to enact substantial changes to laws, which are firmly rooted in the linear model, remains limited” (BP5).

Acceptance of the solution by stakeholders is yet another barrier to PSS (BP1; BP3). For example, acceptance from architects. Do they want to implement product service, which may require limiting their choices and following standardized options? They are accustomed to having a wide range of choices for their projects, but this may need to be streamlined for PSS to be viable (BP1). The upper mentioned points to the next barrier: *the lack of standardization* (BP1; BP2) in factors such as dimensions, finishing, and color, challenging reusability. Therefore, architects must recognize the importance of balancing fashion trends with sustainability (BP4).

Another challenge is that buildings are not products, and many materials used in construction are low-profile and low-tech, such as gypsum, bricks, stones, and wood (BP6). These materials have low or no value in the end. PSS works if a business case exists; companies will not use it even if it leads to environmental gains, as companies are here to create value (BP6). Therefore, companies need to learn how to make money with fewer materials, but they are currently incentivized to sell more. For example, limiting the amount of CO2 emissions could be a solution and could incentivize take-back and buy-back guarantees, but it is hard to use PSS as a solution for the entire built environment (BP6).

There are some barriers due to proportionality (BP7), as the *size of the company and partners* matter (BP8). When a company is shifting to PSS, challenges may arise as the company may need to expand horizontally and vertically (BP7). To develop a viable offering, it should be ensured that the transition to PSS is appropriate and aligned with the *company's size, capabilities* (especially risk management), and *resources*. The shift involves various resource-intensive stages such as design, production, assembly, maintenance, financing, disassembly, and reuse. However, small companies face challenges in investing resources in all these areas and gaining *trust* due to a lack of track record. Convincing investors, including banks, requires careful consideration of the company's size, and the *partners* involved play a significant role (BP7). However, Companies often overestimate what they can do (BP2; BP7), especially when they undergo a transition (BP7).

Storing the products is challenging, as you must have much stock ready to reuse them (BP4). Furthermore, PSS are often highly localized and cannot be easily replicated in other areas or countries due to country-specific conditions. As mentioned, “our model is developed considering the conditions in the Netherlands: it may also work for Belgium, but it is not applicable in France” (BP5). Lastly, *consumer acceptance* is a barrier to companies as they are not open to new solutions (BP8).

The attractiveness of virgin materials stems from their cost-effectiveness, while the higher cost of repairs can be attributed to elevated labor expenses. Consequently, individuals may question the rationale behind repairing a product when they can purchase a new one at a more affordable price. “Those are not the right incentives in the system, and they need to change from the top down” (BP5).

4.2 List of Barriers for Companies

This section provides an overview of the barriers identified via the literature review and interviews. The combined list of the barriers identified is presented below in Table 13. As expected, the number of barriers recognized from the literature is more compared to interviews.

Table 13: The combined list of barriers for companies identified via literature review and interviews.

| PSS Barriers for Companies | | | |
|----------------------------|----------------|---|-------------------------|
| # | Categories | Specific barrier | Source |
| 1 | Customers | Long-term relationship/contracts | Literature & Interviews |
| | | Lack of consumers interest | Literature & Interviews |
| | | Reduced care for products | Literature |
| | | Not able to communicate one-on-one with clients | Interviews |
| 2 | Supply chain | Lack of standardization | Literature & Interviews |
| | | Lack of partners | Literature & Interviews |
| | | Lack of information exchange between supply chain actors | Literature & Interviews |
| | | lack of long-term perspective by suppliers | Interviews |
| | | Lack of trust and collaboration in the supply chain | Literature & Interviews |
| | | Stakeholders resistance | Literature & Interviews |
| | | Storing of products to reuse | Interviews |
| 3 | Organizational | Organizational complexity or administrative burden & responsibility | Literature & Interviews |
| | | Conflicts between business functions | Literature |
| | | Change in organization processes and mindset | Literature |
| | | Reverse logistics | Literature |
| | | Lack of organizational commitment | Literature |
| | | Lack of business strategy | Literature |
| | | The BM cannot be easily replicated in other areas | Interviews |
| 4 | Resources | Lack of abilities and competencies | Literature & Interviews |
| | | Lack of human resource | Literature & Interviews |
| | | Lack of financial resources | Literature |
| | | Proportionality, companies size, and capability | Interviews |
| | | Lack of information/data | Literature |
| 5 | Knowledge | Lack of knowledge and understanding | Literature |
| | | Inability to quantify economic and environmental savings of PSS | Literature |
| | | Inability to deliver high-quality products | Literature |
| | | Lack of sustainability awareness | Literature |
| 6 | Financial | Profitability of existing business models | Literature |
| | | Financial risk due to the long service life of buildings | Literature & Interviews |
| | | Profit calculation | Literature |
| | | R&D investment in system and service integration | Literature |
| | | High upfront costs and lower upfront profits | Literature & Interviews |
| 7 | Technology | Design challenges to create durable products | Literature |
| | | Lack of digitally-enabled services and technological readiness | Literature |
| | | Lack of an effective information management system | Literature |
| | | Lack of external infrastructure and technologies | Literature |

| | | | |
|----|----------------------|--|-------------------------|
| | | Building materials are low-profile and low-tech | Interviews |
| 8 | Regulation or policy | Change in ownership of physical elements in the system | Literature & Interviews |
| | | Lack of supportive rules and regulations | Literature |
| | | Lack of methods and specific guidelines for the transition | Literature |
| | | Lack of sufficient governmental interventions | Literature |
| 9 | Environmental | Rebound effect | Literature |
| | | Environmental benefits are not always significant | Literature |
| 10 | Social | Differences in large consumer groups | Literature |
| | | Resistance to established local habits and behavior change | Literature |
| | | Resistance to adopt PSS by companies as customers misuse | Literature |
| | | Cultural acceptance | Literature & Interviews |

4.2.1 Frequency and Importance of Cited Barriers

This sub-section comprehensively analyzes the barriers identified in the literature and interviews, focusing on their frequency and importance. It specifically highlights the significance of financial barriers along with other prominent categories. The assessment of barriers' importance is based on the number of studies citing these barriers and the mention of these barriers in interviews.

As depicted in Figure 19, the most cited barrier, mentioned eighteen times in the literature, was the lack of knowledge and understanding. The second most frequently cited barriers were the lack of abilities and competencies and high upfront costs and lower upfront profits, which were mentioned fourteen times. Lack of trust and collaboration in the supply chain was ranked third, cited eleven times. The barriers listed as fourth were lack of consumer interest, financial risk due to the long service life of buildings, and lack of supportive rules and regulations, mentioned ten times. The remaining barriers were cited less than ten times, with around half being cited at least five times or more.

In addition, as shown in Figure 21, the most cited barrier from the interviews was high upfront costs and lower upfront profits, which was mentioned four times. Organizational complexity or administrative burden, responsibility and proportionality, company size, and capability were each mentioned three times, while the remaining barriers were only mentioned once or twice.

Figure 20 illustrates the cumulative count of citations for each category based on specific barriers identified in the literature, while Figure 22 depicts the same information from the interviews. It is evident that financial, organizational, resources, knowledge, and supply chain categories are cited with a higher frequency, respectively. On the other hand, barriers in environmental, technology, and social categories are respectively least mentioned.

As shown in Figure 20, the most cited barrier category in the literature was the financial barriers category, including six barriers cumulatively mentioned 41 times. In addition, as visualized in Figure 22, the financial barriers category was one of the most cited barriers in the interviews, cited 6 times. The most cited specific barrier of the group was high up-front investment costs and low up-front profit, which was mentioned 14 times in the literature and four times in the interviews. This particular barrier was the first most quoted in the interviews and the second most cited in the literature.

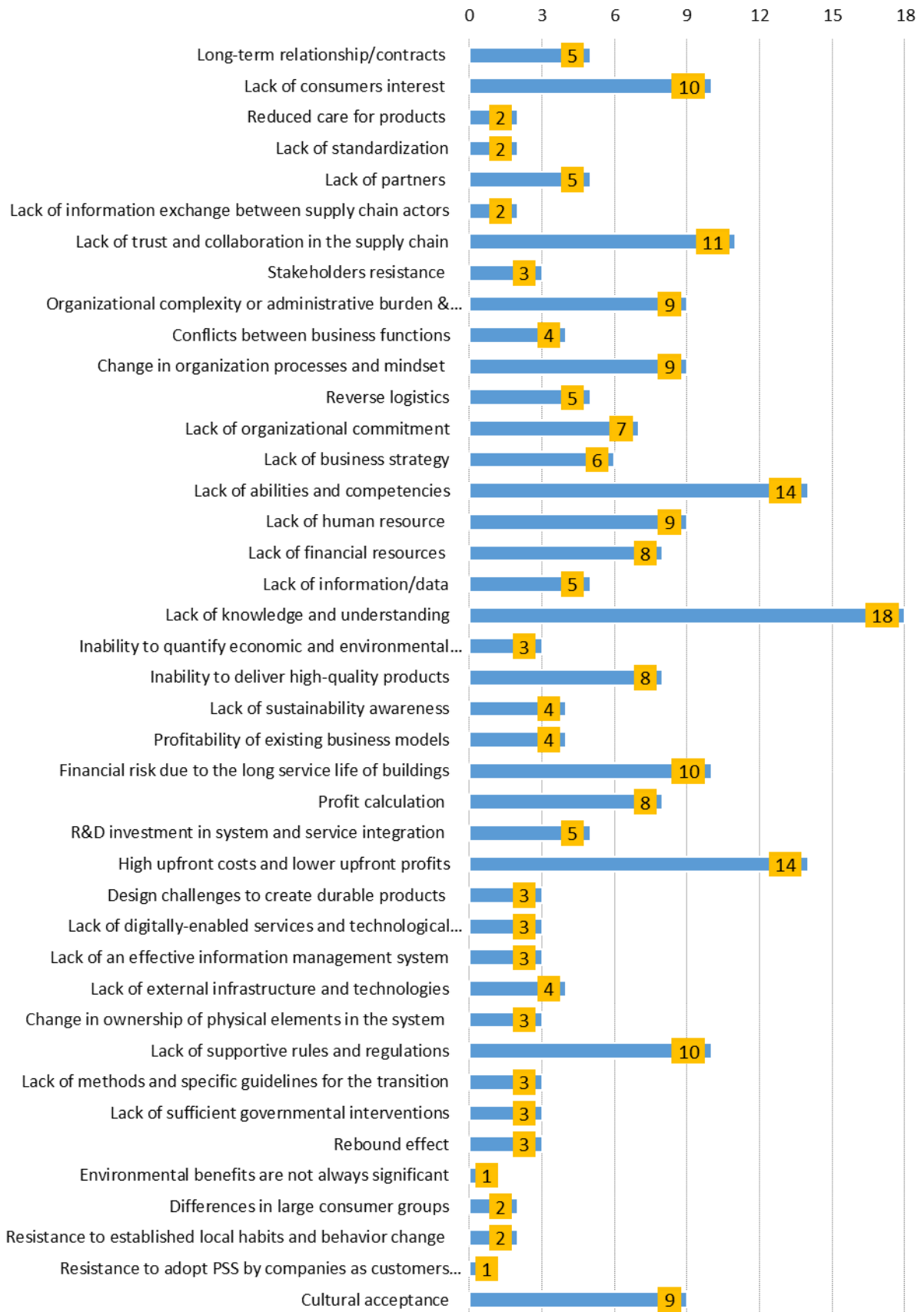


Figure 19: The number of times each barrier was cited in the literature; own figure.

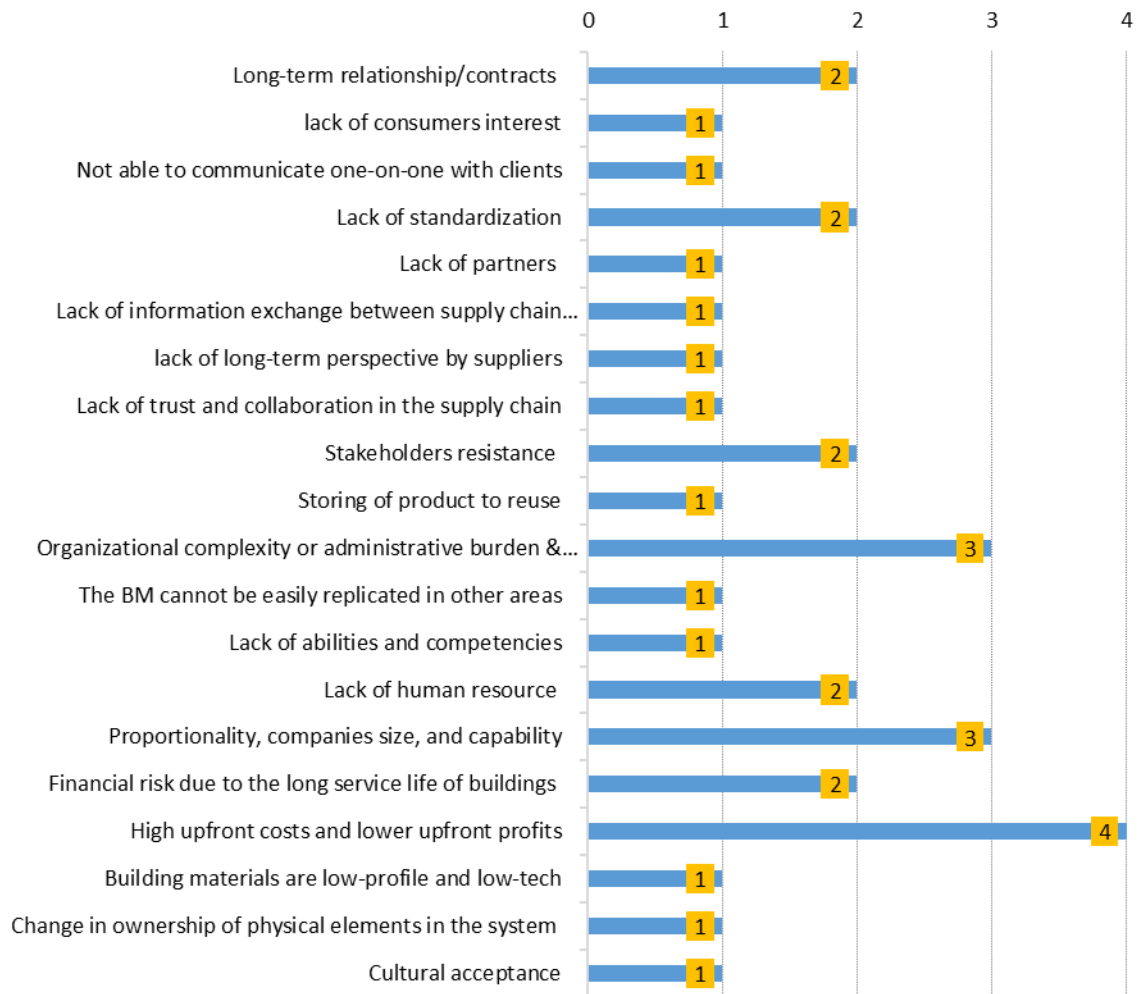


Figure 20: The number of times each barrier was cited in the interviews; own figure.

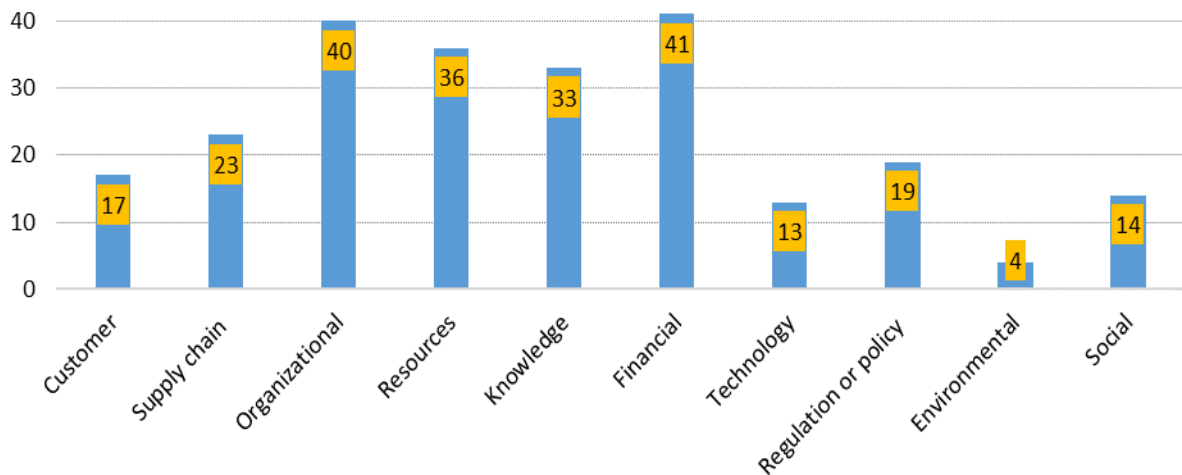


Figure 21: The cumulative number of citations for each category based on specific barriers from literature; own figure.

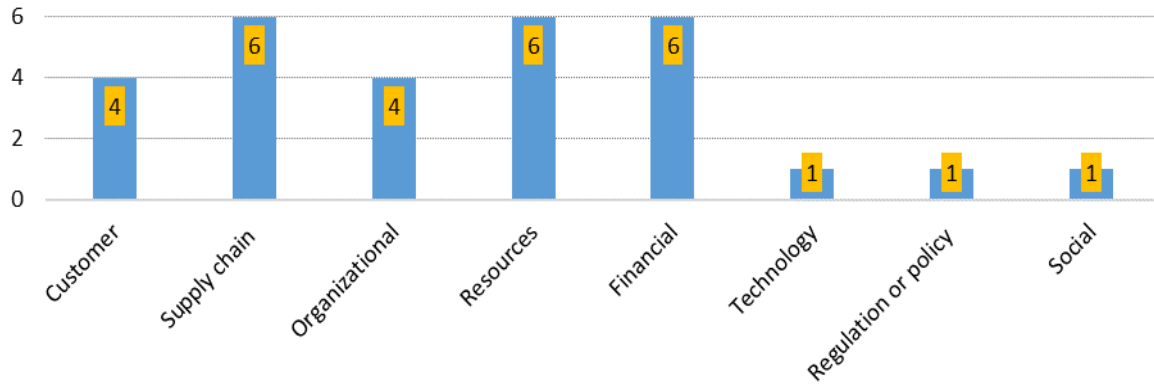


Figure 22: The cumulative number of citations for each category based on specific barriers from interviews; own figure

4.2.2 Categorizing Barriers: Internal, External, and Mixed Types

As shown in Table 14, this study divides the identified barrier categories into internal, external, and a mix of the two to understand the challenges companies face when adopting PSS in the building sector. Internal barriers arise within the company, such as organizational, resources, and knowledge. External barriers are challenges caused by factors beyond the company's control, such as regulatory or policy and environmental and social constraints. The mixed category is barriers that companies cannot immediately control but can influence, such as stakeholder participation, consumer acceptance, and supply chain complications.

Table 14: Barriers categorization into internal, external, & mixed; the citation is based on Table 4 and Table 5.

Classifying barriers to PSS as internal and external barriers is complex, as some could arise from internal and external issues. For example, the supply chain can fall under internal because of inefficient internal processes, lack of coordination among departments, or resource constraints within the company requiring internal efforts to improve. However, supply chain challenges can also be due to external factors, such as disruptions in the external supply chain, changes in market demand, or supplier reliability.

This study focuses on internal and most barriers in the mixed categories identified from the literature review and interviews because the challenges within a company's context can be addressed through internal efforts, such as changes in organizational processes, resource allocation, knowledge management, and financial planning. Companies do not have much control over external barriers; of course, companies have some influence on external issues, but not sufficient to address them, especially if they are alone in their endeavors.

| Categories of PSS barriers | | | |
|----------------------------|----------------------|----------|------------|
| # | Barrier category | Type | Citations |
| 1 | Customers | Mixed | (BP1; BP5) |
| 2 | Supply chain | Mixed | [4] |
| 3 | Organizational | Internal | [4], [10] |
| 4 | Resources | Internal | [10] |
| 5 | Knowledge | Internal | [4],[10] |
| 6 | Financial | Mixed | [4],[10] |
| 7 | Technology | External | [4], (BP6) |
| 8 | Regulation or policy | External | [4],[10] |
| 9 | Environmental | External | [10] |
| 10 | Social | External | [10] |

Section 5.1 of this chapter aims to identify the drivers of PSS adoption, and section 5.2 proposes potential solutions to address the barriers faced by companies in the building sector when adopting PSS. The drivers and solutions were carefully examined through a literature review and interviews with industry experts. Section 5.2 focuses on the barriers identified as internal and mixed categories in section 4.2.2 of Chapter Four. The findings are visually depicted in a matrix diagram, illustrating the linkage between each barrier and their respective solution(s).

5.1 PSS Drivers

According to Annarelli et al. (2016), drivers are the motives underlying the choice to develop/implement a PSS. This study considers the term driver as a condition, strategy, or decision that motivates or causes a change. For example, a company may be encouraged to implement PSS to increase revenue, differentiate themselves from competitors, or improve customer satisfaction and loyalty. The PSS benefits presented in section 3.6 may drive its adoption; however, this section avoids repeating them.

5.1.1 PSS Drivers from Literature

A summary of the drivers of PSS identified from the literature is presented in Table 15. The drivers are divided into those affecting companies and those influencing customers. The drivers impacting companies, which constitute the primary focus of the study, are further categorized into internal and external factors.

Finding new market opportunities (Aguerre et al., 2018; Annarelli et al., 2016; Ceschin, 2014) and improving the competitive position are the primary internal drivers of adopting PSS for companies (Annarelli et al., 2016; Ceschin, 2014; Vezzoli et al., 2015). Business in developed economies face rising competition from nations with low-cost labor, which result in sheer price competition and, ultimately, lower profit margins. Companies in various sectors have realized that competing based on product quality and the effectiveness of operational and production processes is insufficient (Ceschin, 2014). Besides, product-based businesses have shown to be relatively easy for rivals to replicate, but it is more challenging to copy PSS (Annarelli et al., 2016). This has caused many companies to identify the need to move up the value chain and focus on strategically integrating products and services to sustain competitive advantage and business profitability. Furthermore, implementing a PSS strategy is often driven by companies' "desire to differentiate their offers" to address new customer needs effectively (Annarelli et al., 2016; Ceschin, 2014; Sarancic et al., 2022).

Concerning the external drivers, strict environmental regulation requires companies to change their business operations (Mont, 2002). Policies such as pollution charges, fiscal incentives, and extended product liabilities can encourage companies to enhance their solutions to reduce their environmental impact. PSS-oriented BM can be a strategy for current and future requirements (Ceschin, 2014). Based on Annarelli et al. (2016), cooperating with authorities

(governments) is the second most cited driver of PSS for companies in the literature. It has to be emphasized that while these policy initiatives support improved products and services, they do not necessarily drive companies to develop PSS. The growing public awareness of environmental and socio-ethical issues is another key driver. However, it should also be stressed that often in response to this need, companies may turn to “greenwashing” methods, the production of supposedly sustainable products and services (Ceschin, 2014).

Moreover, customers want reduced risk and liability associated with handling a product. PSS can address this requirement by freeing customers from product responsibility which is typical in B2B relations. However, there are some barriers to ownerless consumption in B2C relationships. Private clients are more inclined to accept PSS when products are expensive, not regularly used, or need costly maintenance or storage space (Ceschin, 2014). According to Annarelli et al. (2016), building customer relationships is the most cited driver of PSS in the literature, which is confirmed by other studies (Sarancic et al., 2022; Sousa-Zomer & Cauchick-Miguel, 2019).

Table 15: Drivers of PSS for companies and consumers; the citations are based on Table 4.

| Drivers | | Citation | |
|-----------------------------|---|--|------------------|
| Drivers for Company | Internal Drivers | The need to find new market opportunities, extend existing offers, and access new market | [3], [31], [45] |
| | | Increasing competitive positions, protecting market share | [3], [10], [45] |
| | | Differentiate their offers, lock out competitors, and unique sell proposition | [3], [44], [45] |
| | | Environmental issues, when liked to economic savings | [3] |
| | | Best utilization of assets | [45] |
| | | Stable cash flow | [31], [44] |
| | | Higher profit margin | [31] |
| | | Incentivize innovation and quality | [31], [44] |
| | | Enhance raw material security & reproducing | [31], [45] |
| | | Gather valuable data | [31], [44] |
| | External Drivers | Stringent environmental regulation | [3], [28] |
| | | Cooperating with authorities (local government) | [45] |
| | | Reducing environmental costs | [44], [45] |
| | | Growing public concern about the environment and socio-ethical issues | [3] |
| | | Building relationships with customers | [45], [41], [44] |
| Suppliers engagement | | [45], [44] | |
| Drivers for Customer | Reduced risks and liabilities associated with products | [3] | |
| | Removing administrative tasks and responsibilities from customers | [10],[31] | |
| | Cutting initial investment & running costs or lower upfront investments | [10], [31], [44] | |
| | More customization (improve function flexibility) and high quality | [10], [31] | |

5.1.2 Empirically Identified Drivers: Insights from Interviews

A key drive of PSS is its circularity and sustainability potential; as mentioned by one of the interviewees, “We offer PSS due to its circularity and sustainability potential” (BP3). In the traditional BM, following the project specifications, every project requires developing something new, resulting in unique and one-of-a-kind solutions (BP1). Therefore, companies utilize their resources to cope with developing solutions. However, with PSS, long-term responsibility becomes crucial, leading to developing new standardized concepts that allow for extended product lifespan and reuse.

PSS eliminates the need to reinvent the wheel for each project (BP3) and provides the room to focus on offering flexibility (BP1; BP3), modularity, reusability, and savings (BP3). For example, customers can modify their space based on the changing uses of a building, such as altering high ceilings to low ceilings or partitioning the space. It is far easier and faster to assemble and disassemble; for instance, “disassembling walls are five times easier with product service” (BP3). These walls can be placed and moved endlessly and could last more, making them reusable (BP3; BP4). Furthermore, at the end of the lifecycle, the interior walls designed for reusability are not demolished but disassembled and reused, generating revenue rather than costs (BP3). This shift in the BM also changes the client's perspective, focusing on the product's value today and in the future (BP1).

Companies offering PSS have better assurance of product lifecycle, risk management, and sustainability, translating to easier transactions and more consumer trust (BP7). Besides, adopting PSS can provide a competitive advantage for companies, ensuring business continuity and profitability (BP7; BP8). Companies also consider different BMs to achieve financial gains and address supply chain issues (BP8).

One interviewee expressed their motivation to adopt PSS in the construction sector, driven by an inherent desire to promote environmental sustainability through waste reduction and circularity and contribute to a better and more resource-efficient world. For example, half a million kitchens in the Netherlands are discarded and incinerated annually, with approximately two hundred thousand originating from the professional rental market. Leading to a wasteful depletion of materials and resources; “we must create a value chain in the building industry” (BP5).

In addition, PSS contributes to CO₂ emissions reduction through optimized production and recycling processes. For example, as mentioned by (BP4), the CO₂ emission of a 500 square meter partition wall (Clear vision 100) using the linear method resulted in 60 tons of CO₂ emissions due to production, transport, and recycling. However, the circular model, which excludes recycling, resulted in 34 tons of CO₂ emissions from production and transportation. In the first cycle of the circular model, emissions were also high but reduced to 0.2 tons in the second life due to transportation emissions only. The circular model significantly reduces CO₂ emissions compared to linear models (BP4).

In conclusion, providing PSS in the building sector is motivated by circularity, flexibility, reusability, cost savings, and reducing CO₂ emissions. The transition to a customer-centric approach and assurance of sustainability and business continuity are also key drivers.

5.2 Potential solutions

This section represents the solutions for barriers specified in section 0 as internal and mixed types. In the context of this study, a solution (enabler) makes a specific action or outcome possible or facilitates its progress or success. For example, a company can access new technology and has competent employees to enable an innovative offering. This study identified the following potential solutions for the barriers specified.

5.2.1 Effective Leaders

For companies to overcome internal barriers, leaders in the top-level management who understand the concept of servitization are necessary (Baines & Lightfoot, 2013). They can substantially facilitate the transition to PSS (Kroon, 2020) by enabling information exchange, encouraging a long-term perspective, building trust and collaboration among stakeholders, managing change resistance, addressing organizational complexity, and developing team competencies. Moreover, they are critical in strategically allocating resources, creating a culture of sustainability, and assessing and converting the impact of PSS to stakeholders. In addition, they can form cross-functional teams, provide training and support, and align incentives to encourage the adoption of the new BM. Influential leaders are the enablers of all the following solutions. They can create a working environment that fosters innovation, embraces change, and drives the successful implementation of PSS.

5.2.2 Separated Business Units

Companies can have separate business units, with one team focusing on services and the other on traditional products. The service-oriented department should prioritize service quality and its lifecycle value, addressing challenges and barriers related to PSS. This approach facilitates onboarding technical experts, emphasizes long-term relationships and knowledge retention for contract execution, fosters corporate risk management through diversified revenue streams, and provides resilience against business failure. Effective communication between these units is required (Kroon, 2020) for information exchange and coordination, helping to reduce disputes within the company's business functions. Moreover, the specialized expertise in each unit and the combined entity can leverage complementary strengths to enhance the management of financial resources, mitigate risks associated with the long service life of buildings, and assess PSS's economic and environmental savings. Therefore, having separate units can streamline processes and improve expertise in offering PSS.

5.2.3 Train Existing Personnel and Hire Additional Personnel

Companies transitioning to PSS, particularly in the building sector, require specific capabilities and knowledge. The abilities and expertise needed to produce and sell products differ significantly from those required to offer PSS. As a result, companies must acquire new skills and expertise, including adopting methods, tools, and lifecycle costing techniques, and undertake organizational restructuring to excel in developing, designing, and providing PSS. In addition, companies must establish performance indicators and metrics to measure their proficiency and effectiveness in delivering PSS. Companies need to train existing personnel to accomplish these objectives and may also consider hiring additional staff (Vezzoli et al., 2015).

To ensure circularity and sustainability, companies should prioritize understanding how their products can be transformed. Implementing strategies that enable the slowing and closing of material and energy loops is essential for achieving product and BM circularity, as elaborated

in section 3.4. Furthermore, companies need to identify and design sustainable BMs and determine the PSS types with the greatest potential for sustainability. In-depth insights into these strategies can be found in section 3.5. PSS's sustainability and circularity aspects are significant in securing funding, as financing is a major barrier for companies offering PSS.

5.2.4 Long-term Relationships

Building long-term relationships with customers is crucial for companies. This requires accepting and committing to long-term engagement, which can be reinforced through multiple touchpoints. Touchpoints such as client inquiries, personalized offers, regular updates, and attentive customer support enable companies to engage with consumers actively, foster meaningful relationships, and strengthen their commitment to maintaining long-term connections. Even if customers discontinue their engagement, their feedback and comments can provide valuable insights for improving products, services, and customer experience. Consequently, companies can benefit by cultivating enduring consumer relationships through various touchpoints and leveraging customer feedback (Kroon, 2020).

Furthermore, when implementing PSS partnering with other actors (Schoonover et al., 2021) and building strong relationships (Kroon, 2020) become crucial. According to Mont (2002), partnering with other actors is an essential aspect of PSS for building capabilities and relationships. By partnering with other actors, companies, especially early-stage ones with limited resources, can leverage their expertise, knowledge, information, and network, tapping into complementary competence to promote innovation, gain market access, share risks, and achieve other strategic advantages required for adopting PSS (Schoonover et al., 2021).

Another effective strategy is business integration, which involves building partnerships, merging with other firms, and cultivating long-term cooperation. It's important to note that in this study's context, integration does not necessarily mean acquiring or controlling the entire supply chain. Instead, it entails collaborating and aligning companies' strategies with other actors for mutual benefit, including horizontal and vertical integration.

5.2.5 Horizontal Integration

Horizontal integration is a strategic approach wherein a company partners with and aligns its strategies with other businesses operating within the same supply or value chain level (BP7). This approach enables the creation of a comprehensive one-stop-shop for customers, offering complementary products and services. Consequently, it strengthens the company's market position and provides a competitive edge by capitalizing on the expertise of partner businesses, promoting collaboration, facilitating knowledge sharing, and unlocking innovation potential. For example, a façade company aiming to provide a holistic solution may collaborate with an insulation company, integrating their expertise in exterior aesthetics and thermal insulation. This collaboration results in a comprehensive solution that ensures both aspects. As a result, customers benefit from a single provider that delivers an all-encompassing solution, enhancing convenience and ensuring optimal performance.

5.2.6 Vertical Integration

Vertical integration is a business approach in which a company aligns its strategies with the entire supply or value chain (Baines & Lightfoot, 2013), including suppliers and consumers (BP7). The approach is also highlighted by Neely (2008), who proposes a specific type of PSS known as integration-oriented PSS, as presented in section 3.3. Vertical integration offers

companies numerous advantages, including control over the supply chain, cost savings, improved operational efficiencies, enhanced innovation and customization capabilities, and a competitive edge.

In addition, for companies offering PSS, it is crucial to have control or influence over the design and availability of the product for reuse. For example, in the case of a company offering kitchen-as-a-service, collaboration with a water tap provider to develop circular and sustainable taps becomes essential. These taps can be characterized by standardization and durability, designed to be easily assembled, maintained, and disassembled. The company can then return the disassembled taps to the supplier for storage and future reuse.

5.2.7 Use Knowledge and Experience in other Sectors

Utilizing knowledge and experience from other industries, such as manufacturing companies, can benefit companies in the building sector (Cook et al., 2012). The understanding and awareness level of the PSS concept vary between the manufacturing and construction industries, and manufacturing companies possess valuable knowledge and experience in this area. Using the expertise of manufacturing companies, companies in the building sector can enhance their implementation of PSS and capitalize on the lessons learned from successful product-service offerings.

5.2.8 Use Learning by Doing

Companies can employ the learning-by-doing approach to better understand the factors influencing PSS adoption (Cook et al., 2012). Companies in the building sector can embark on their PSS journey by undertaking small-scale business initiatives, establishing separate business units within their organization, or operating alongside their primary business (Kroon, 2020). By starting in a B2B environment, they can gain valuable experience before venturing into the more challenging B2C market and expanding on a larger scale. As companies progress, it becomes essential for them to adapt and make improvements in response to evolving circumstances (Schoonover et al., 2021). This highlights the significance of experimentation in BM innovation, particularly in sustainable BM innovation (Geissdoerfer et al., 2017), as it is impossible to predict outcomes with certainty.

5.3 Solutions Matrix: Bridging Barriers

Table 16 provides a matrix diagram that presents recommended solutions on the right-hand side, introduced in the previous section. The left side of the matrix consists of barriers, categorized as internal and mixed in Table 14, section 4.2.2, and presented in Table 13. The diagram explains which solution can help overcome specific barriers. It is a visual decision-making tool, enabling companies to prioritize efforts and allocate resources effectively. The effectiveness of solutions varies depending on the barrier category. Vertical integration effectively addresses supply chain and resource management barriers, enhancing coordination and control. Establishing long-term relationships with suppliers is particularly effective in overcoming supply chain barriers, fostering collaboration and efficiency. Effective leadership at the top-level management is crucial for addressing organizational barriers, ensuring strategic alignment, and effective decision-making. Lastly, training and hiring additional personnel are more effective in tackling knowledge-related barriers, enhancing expertise and capabilities. Thus, companies must prioritize based on the specific barriers they face to optimize their efforts in successfully navigating adopting PSS in the building sector.

Table 16: A matrix diagram showing which recommended solution is an enabler for which barrier.

| # | Categories | Barriers | Solutions | | | | | | | | |
|---|----------------|---|-------------------|--------------------------|-------------------------|--------------------------|-------------------------|------------------------|----------------------|--|-----------------------|
| | | | Effective leaders | Separated business units | Train existing personal | Hire additional personal | long-term relationships | Horizontal integration | Vertical integration | Use expertise of manufacturing companies | Use learning-by-doing |
| 1 | Customers | Long-term relationship/contracts | | X | X | X | | | | X | X |
| | | Lack of consumers interest | | | | | X | | | X | |
| | | Not able to communicate one-on-one with clients | | X | | X | | | | | |
| 2 | Supply chain | Lack of standardization | | | | | X | | X | X | |
| | | Lack of partners | X | | | | X | X | X | | |
| | | Lack of information exchange between supply chain actors | | | | | X | | X | | |
| | | Lack of long-term perspective by suppliers | X | | | | X | | X | | |
| | | Lack of trust and collaboration in the supply chain | X | | | | X | | X | | |
| | | Stakeholders resistance | X | | | | X | X | X | | |
| | | Storing of product to reuse | | | | | X | | X | | |
| 3 | Organizational | Organizational complexity or administrative burden & responsibility | X | X | X | X | | | | | |
| | | Conflicts between business functions | X | X | | | | | | | |
| | | Change in organization processes and mindset | X | X | X | X | | | | | X |
| | | Reverse logistics | X | X | X | X | X | X | X | X | X |
| | | Lack of organizational commitment | X | | | | | | | | |
| | | Lack of business strategy | X | | | | | | | | |
| | | The BM cannot be easily replicated in other areas | X | | X | X | | | | X | |
| 4 | Resources | Lack of abilities and competencies | X | X | X | X | | X | X | | X |
| | | Lack of human resource | | X | | X | | X | X | | |
| | | Lack of financial resources | | X | | | | | X | | |
| | | Proportionality, companies size, and capability | | X | X | X | X | X | X | | |
| | | Lack of information/data | | | | | X | X | X | X | X |
| 5 | Knowledge | Lack of knowledge and understanding | X | | X | X | | | | X | X |
| | | Inability to quantify economic and environmental savings of PSS | | | X | X | | | | | |
| | | Inability to deliver high-quality products | | | X | X | | | | X | |
| | | Lack of sustainability awareness | X | | X | X | | | | | |
| 6 | Financial | Profitability of existing business models | | X | | | | | | | |
| | | Financial risk due to the long service life of buildings | | X | | | | | X | | |
| | | Profit calculation | | | X | X | | | | | |
| | | R&D investment in system and service integration | | | | | X | | X | | |
| | | High upfront costs and lower upfront profits | | | | | | | X | | |

To provide an example, the following paragraphs elaborate on how these solutions can help contractor companies overcome the reverse logistic barrier to PSS in the building sector.

Effective leaders at the top-level management play a critical role in facilitating the reverse logistics process by enabling information exchange, fostering collaboration, and managing resources, including human resources. These leaders are required to manage the complexity of the task and enable all the other solutions presented.

Separate business units can streamline the reverse logistic process as dedicated personnel can focus on each task. Establishing dedicated processes and infrastructure is crucial for handling reverse logistics in the construction sector, including setting up collection points for product returns, implementing effective sorting and categorization systems, and partnering with logistics providers specializing in reverse logistics. By integrating these processes into their operations, companies can streamline returned products' flow and ensure proper handling and storage.

Utilizing the room offered by separated business units, companies can *train existing personnel* and *hire additional staff* with the required capabilities to ensure focused expertise and efficient handling of returned products. For example, staff specializing in disassembling, storing, and reusing products.

Establishing *long-term relationships* and agreements with suppliers is crucial for effective reverse logistics. Companies may face challenges storing all returned products due to storage shortages or the financial resources invested. By returning the products to suppliers for an agreed price, companies can reinvest their financial resources and avoid unnecessary storage expenses.

In addition, partnering with other actors and building strong relationships enables innovation, market access, and risk-sharing. *Horizontal integration* can help manage products provided by multiple providers, such as a facade system involving an insulating company. Clear agreements should be made regarding responsibilities and actions for comprehensive solutions, especially the ones with different lifespans. On the other hand, *vertical integration* aids in dealing with supply chain issues and influencing design and operational efficiencies. Information exchange agreements between suppliers and PSS providers are necessary for effective collaboration. For example, the supplier needs information on return, reuse, and customer feedback, while the PSS provider needs information and control over availability and price for reuse.

Furthermore, capitalizing on *knowledge and experience from the manufacturing sector* enhances implementing design practices prioritizing disassembly and reuse, such as modular and standardized construction techniques, easily separable materials, and proper labeling and documentation, enabling efficient dismantling and recovery of materials and products for reuse. Besides, partnering with service providers in the manufacturing sector to offer maintenance and reintegration services for returned building components is beneficial. These collaborations enable companies in the construction sector to tap into external expertise, and leverage shared resources to create a closed-loop system.

Lastly, embracing a *learning-by-doing* approach allows companies to gain experience, adapt strategies, and make improvements as they navigate the complexities of the reverse logistics process for PSS in the building sector.

This chapter is comprised of two sections. Section 6.1 discusses the study's results; it highlights findings on PSS from literature and practice, including identified barriers and solutions. Section 6.2 outlines the study's limitations on methodology, sample size, focus, and external validity.

6.1 Results

This section discusses the results of this study. It provides insight and analysis of results presented in Chapters 3, 4, and 5.

This section discusses the study's findings, providing insights and analysis of the study's results presented in chapters three, four, and five.

6.1.1 Product-Service System

Several definitions of PSS have been proposed in the literature, chronologically presented in Table 6. These definitions primarily focus on a system meeting customers' needs through tangible products and intangible services. While eight of the seventeen definitions highlight the environmental impact, two mention the involvement of a network of actors and supporting infrastructure, and one emphasizes social aspects and partnerships.

Although fewer definitions emphasize the network of actors, supporting infrastructure, collaboration, and partnership, it is essential for companies offering PSS in the building sector to consider these elements to adopt PSS successfully. Based on the scope and context of this study, as well as the definitions in Table 6, PSS, or especially a sustainable PSS, could be formulated as follows: an integrated system of tangible products and intangible services, networks of actors, and supporting infrastructure where the degree of integrations depends on the requirements of a specific system, conveniently addresses customers' needs compared to product-oriented solutions, striving for the competitive advantage of providers, resulting in long-term relationships with both market partners and customers, and can lead to sustainable and circular practices.

6.1.2 PSS Classification

Several classifications of PSS are available in the literature, presented in Table 7. Among these, the classification proposed by Tukker (2004) is well-known and widely referenced. Although Mont (2002) introduced the concepts of use-oriented and result-oriented PSS, most studies build upon Tukker's classification.

The classification presented in Table 7 consists of two groups: one focusing on offerings and the other on transforming a company into a service provider. These classifications are general and applicable to companies of different sizes operating in various sectors.

6.1.3 PSS Circularity and Sustainability

The concept of PSS initially emerged in response to the growing demand for more sustainable and environmentally friendly businesses. Over time, PSS has evolved as a strategy for companies to differentiate themselves and foster customer loyalty by offering comprehensive and customized experiences. Moreover, sustainability and circularity should hold particular relevance for PSS in the construction sector due to their goals of promoting circularity, sustainability, and CO2 emissions reduction.

However, it is important to note that circularity and sustainability are not inherent in PSS. Different types of PSS possess varying degrees of sustainability potential. Theoretically, result-oriented PSS exhibits the highest potential for sustainability. Therefore, companies aiming for maximum sustainability should focus on developing result-oriented PSS.

To achieve sustainable outcomes, PSS providers must actively influence the design of their products and systems, considering sustainability factors and incorporating circularity concepts to minimize waste and foster resource efficiency. Without these considerations, the product and the system may not contribute effectively to circularity and sustainability.

Understanding the distinction between a circular and sustainable PSS and a PSS primarily focused on long-term relationships is crucial for businesses. This differentiation relies on carefully considering the product and system design and the influence exerted by providers. Circular PSS can be identified by incorporating essential circularity concepts, such as slowing and closing resource flow loops, which promote sustainable practices and minimize waste. Additionally, evaluating the integration of sustainability factors outlined in section 3.5, such as design for the environment, allows for a comprehensive assessment of the overall sustainability of a PSS. By actively embracing these circularity concepts and sustainability factors, a PSS cultivates strong customer relationships and contributes to a more environmentally conscious and efficient approach.

6.1.4 PSS Offerings in the Building Sector

Among the interviewed companies, seven were actively experimenting with or providing PSS, primarily targeting B2B relationships and clients like government institutions and sustainability-focused companies. In the building sector, PSS implementation is still in the experimental phase. This experimental implementation allows companies to develop expertise in PSS, understanding market dynamics, customer preferences, and operational requirements. It serves as a valuable learning process for refining PSS offerings.

Initial PSS offerings focus on maintenance and buy-back guarantees, paving the way for performance-based PSS. Transitioning to performance-based PSS presents challenges and opportunities involving contract redefinition, monitoring systems, and process alignment. Overcoming these challenges enables customer satisfaction strategies and positive environmental outcomes, offering competitive advantages and sustainability improvements for companies in the building sector.

PSS is well-suited for expensive, technically advanced products with infrequent usage and minimal influence from branding or fashion. It benefits from predictable lifespans, residual value, standardized elements, and defined and monitorable performance.

6.1.5 Barriers for Companies

The literature review identified 41 barriers, categorized into ten distinct categories. From the interviews, 20 barriers were identified and grouped into eight categories. As expected, the literature review revealed a higher number of barriers compared to the interviews. Notably, the interviews identified no barriers in the knowledge and environmental categories.

While the literature review did not emphasize many environmental barriers to PSS adoption, the knowledge category stood out. *Lack of knowledge and understanding* emerged as the highest cited barrier, mentioned in 18 out of the 45 reviewed papers. Regarding total citations, the knowledge category ranked fourth (see Figure 19). Understanding the disparity between research and practice is crucial, as addressing the knowledge barrier in PSS adoption is essential.

In addition, it is essential to note that a high number of citations for a barrier indicates its significance within the research community. However, the criticality of a barrier is subjective and context-dependent. A high citation count does not guarantee universal agreement on its importance, as researchers may hold different perspectives. Analyzing the content of the cited articles is recommended to develop a nuanced understanding of the criticality of barriers. This involves examining those papers' arguments, evidence, and discussions to comprehend better why a specific barrier is considered significant.

6.1.6 Solutions

Effective leader at the top-level management is a crucial solution, helping overcome 14 out of 31 internal and mixed barriers in PSS implementation (Table 16). Vertical integration mitigates 16 barriers while hiring additional personnel, separated business units, and effective leaders contribute to mitigating 14 barriers. Training existing personal and long-term relationships mitigates 12 barriers, while use-learning-by-doing tackles 6 out of 31 barriers.

Most companies interviewed already utilize separate business units for product and service offerings due to resource limitations and the need for specialized expertise. This strategy addresses administrative burdens, conflicts, and corporate risk management. Although not mentioned by any interviewee, it significantly contributes to corporate risk management as companies prioritize safeguarding their existing BM during PSS experimentation.

The solutions are intricately interconnected, mutually supporting and assisting one another. Effective leaders play a vital role in enabling long-term relationships and facilitating vertical and horizontal integration, while integration fosters the development of long-term relationships, creating a cyclical and mutually reinforcing dynamic.

6.2 Limitations

This section acknowledges the study's limitations. These limitations include possible biases in the literature review method, sample size, interviewees' selection procedures, the sole focus on internal barriers, and a lack of verification of findings in a focus group. The following paragraph explains the limitations and their potential impact.

6.2.1 Methodology

The literature review was conducted using the Google Scholar search engine and the Scopus database, which may have omitted relevant studies from other sources. Besides, the literature

search was restricted to research published in English, which may have resulted in language bias and the removal of significant non-English language publications. Furthermore, only papers published after 2010 were selected for literature review, potentially leaving out some prior research. The study may not have covered all relevant literature completely, thus resulting in gaps in the analysis. These limitations should be considered while interpreting the results and inferences from the literature review findings.

6.2.2 Simple Size and Focus

One limitation of this study is related to the employed literature review method. The study used a specific combination of keywords to identify relevant papers. If a study discussed concepts such as CBM or circularity without explicitly including the term “Product-Service System” or “PSS,” it was automatically excluded. This approach might unintentionally exclude potentially valuable papers that could have contributed to the research. Furthermore, it is important to acknowledge that some studies may have cited the same barriers using the same references, which could impact the diversity of perspectives and potential findings.

The interview sample size was relatively small, with only eight individuals. As seen from Table 13, the number of barriers recognized from the literature is more than those found in the interviews, which was expected. For example, the interviews identified no barriers in knowledge and environmental categories, and the number of barriers recognized in other categories is also limited compared to the literature review. One reason could be that the number of interviews performed was limited. The other reason is that the list of the barriers identified via the literature review was not shared with interviews to avoid potential bias.

Besides, the sample selection procedure may have introduced biases since only companies who claimed commitment to reducing CO₂ emissions, circular and sustainable building practices, or product plus service BMs on their website were included for interviews. While this technique was consistent with the research aims, it may have hindered generalizability. It is critical to evaluate the findings within the context of this selected sample while still recognizing the importance and insights obtained from the interviews.

Furthermore, following the research objectives, the study focused on identifying solutions and enablers to internal barriers that firms have control over. This method ignored external elements outside a company's control on purpose. While the study's narrow focus allowed for a more in-depth analysis of internal barriers, it also implies that external barriers were not considered. As a result, it is critical to interpret the results in light of the limitations and examine external factors' potential influence on the overall findings and conclusions.

6.2.3 External Validity

Another limitation of the study was the lack of verification through a focus group, potentially impacting the generalizability of the findings to different settings. It is important to note that most of the interviewed companies operate in the, with a few also operating in Belgium. Therefore, it is crucial to recognize that the findings may be context-specific, necessitating further research to validate them in other scenarios. However, the study's findings provide valuable insights within the researched context and can serve as a basis for future research in similar contexts.

This chapter concisely answers the research sub-questions and the main question while providing valuable insights for practitioners and researchers. Section 7.1 concludes the research, highlighting the key findings. Section 7.2 provides recommendations for practitioners, offering insights on how the research findings can be applied in practice. Finally, Section 7.3 presents recommendations for further research, proposing potential avenues for future studies that can expand upon the current research and address any remaining gaps in the knowledge.

7.1 Conclusion of the Research

This section first briefly addresses each sub-question and the main research question (main conclusion), providing insightful answers and drawing meaningful conclusions. The findings of this research contribute to the existing body of knowledge in the field and offer valuable insights for practitioners and researchers alike.

Sub-question 1: *What is the state of the art of PSS in the building sector based on scientific literature?*

PSS has evolved from a concept rooted in sustainable business practices to a strategy for differentiation, improved customer loyalty, and customized solutions. PSS, as an integrated system of tangible products, intangible services, networks of actors, and supporting infrastructure, addresses customer needs more effectively than product-oriented solutions, fostering long-term relationships with market partners and customers. It has the potential to lead to sustainable practices and contribute to the development of a CE by facilitating economic growth without excessive resource consumption.

Various definitions of PSS have been suggested in the literature. They primarily revolve around meeting customer needs through tangible products and intangible services. Among these definitions, some prioritize environmental impact, two mention the involvement of a network of actors and supporting infrastructure, and one emphasizes social aspects and partnerships. In addition, various categories of PSS were identified. While some highlighted the options available to companies, from pure product sales to service delivery, others focused on transitioning from product suppliers to service providers.

PSS can serve as both an enabler and a driver of sustainability and CE by promoting resource efficiency, waste reduction, and circularity in material and energy flow loops. The sustainability potential of different PSS types varies, depending on the integration of product users, owners, and makers. Result-oriented PSS, which focuses on outcomes and innovation, theoretically holds the highest potential but requires incorporating the sustainability factors identified in section 3.5.1.

PSS is particularly well-suited for high-cost, technologically advanced products with infrequent usage and minimal influence from branding or fashion. The literature highlights two categories of benefits associated with PSS: internal and external. Internal benefits mainly revolve around the economic aspects for companies, while environmental benefits favor providers and society. However, social benefits are rarely addressed in PSS research.

Despite the concept of PSS being explored in the literature for decades, its practical application in the building sector remains limited. Implementing PSS requires significant changes in internal corporate technology, maintenance, service, and supply chain management upstream and downstream. Companies face numerous challenges in shifting to PSS, including a lack of financial support, the need for organizational restructuring, establishing new customer relationships, developing new contracts, and adopting new economic models. Moreover, there is currently a lack of sufficient policy or regulation to support PSS in the building sector. Nevertheless, sustainability, circularity, and CO₂ reduction can serve as driving forces for the adoption and implementation of PSS.

A well-integrated PSS in the building sector has the potential to combine multiple layers of a building into one system, optimizing overall performance. However, further research and practical applications are needed to realize PSS's potential in the building sector.

***Sub-question 2:** What is the current state of PSS adoption by companies in the building sector in practice?*

The companies interviewed in the building sector focus on four layers providing PSS: stuff, space plan, services, and skin. They offer facade systems, partitions, glass and transparent wall systems, ceiling systems, meeting spaces, doors, windows, interior design, and kitchen-as-a-service, and one of the companies was experimenting with living-as-a-service. However, these services are available in B2B relationships or for clients like social housing but not to individuals. Companies in the building sector focus on clients such as professional rental markets, temporary housing, housing associations, and institutional investors.

Most of the companies in the building sector focus on maintenance and buy-back guarantees, which is assumed to be the first step toward performance-based PSS. Currently, some companies rely on whether their customers desire to disassemble and resell their acquired products. If customers wish, the companies will repurchase the products and offer them to environmentally conscious buyers looking to lessen their environmental impact. Clients interested in PSS are typically government institutions or sustainability-focused companies. On the other hand, most of the companies in the building sector are experimenting with PSS. Companies initially focus on the B2B market due to its established nature, experience, acceptance of leasing, and limited product scope, to develop knowledge, capabilities, and expertise. This technique allows testing and learning before entering the more complex B2C market.

The provision of PSS in the building sector is motivated by circularity and sustainability, flexibility, reusability, cost savings, and decreased CO₂ emissions. Transitioning to a customer-centric strategy and business continuity are also essential drivers. Furthermore, PSS is effective for products with shorter and predictable lifespans, residual value, standardized design elements, and performance that can be defined and monitored.

Sub-question 3: What are the barriers to PSS?

Forty-one barriers were identified using the literature review divided into ten categories, as presented in Table 11. Twenty barriers were identified from interviews and grouped into eight categories, as explained in Table 12. In comparison, 6 of the 20 barriers identified from the interviews differed from those recognized in the literature. The most cited barrier in literature was lack of knowledge and understanding, mentioned in 18 out of 45 papers included in the review. On the other hand, the most cited barrier from interviews was high upfront costs and low upfront profits, which was mentioned in four out of eight interviews. Based on the cumulative number of citations in the literature, the most cited barrier categories were financial, organizational, resources, and knowledge, respectively mentioned 41, 40, 36, and 33 times. While the most mentioned categories from the interviews based on the cumulative number of citations were financial, resources, and supply chain, each mentioned six times. The barriers were combined and classified into internal, external, and mixed categories. The study focused on the internal and most barriers in the mixed categories as companies cannot overcome external barriers.

Sub-question 4: What are potential solutions to the identified barriers of PSS?

The following nine potential solutions were proposed from the literature and interviews which could help companies in the building sector overcome barriers to PSS adoption, which include supply chain and stakeholder categories: effective leaders; separated business units; training existing personnel; hiring additional personnel; long-term relationships; horizontal integration; vertical integration; use knowledge and experience in other sectors; and use learning by doing. Table 16 illustrates the relationship between different solutions and the barriers they can help overcome. The diagram highlights that certain solutions are more effective for specific barrier categories, underscoring the importance of a customized approach. Vertical integration stands out as the most effective solution, addressing 16 barriers. Additionally, hiring additional personnel, utilizing separated business units, and having effective leaders contribute to mitigating 14 barriers. Training existing personnel and fostering long-term relationships help overcome 12 barriers, while use-learning-by-doing addresses 6 out of 31 barriers. The matrix diagram empowers companies to prioritize their efforts and allocate resources efficiently, recognizing that the effectiveness of solutions varies depending on the specific barrier category. Moreover, the solutions are intricately interconnected and mutually supportive.

Main research question: How can companies overcome the barriers to Product-service system business models in the building sector?

The study proposes nine solutions for companies to overcome barriers to PSS adoption in the building sector, which are as follows:

1. Leaders at the top-level management who understand servitization can facilitate the transition by exchanging information, maintaining a strategic and long-term perspective, trust-building and collaboration with stakeholders, and managing change, resistance, risk, resource allocation, and cross-functional team building.
2. Companies can have separate business divisions, focusing on services, traditional products, and mainstream business. This strategy facilitates corporate risk management and onboarding people to acquire knowledge and expertise for execution.

3. Training existing personnel to develop the necessary capabilities and expertise for PSS as the abilities and knowledge needed for building and selling products differ from those required for PSS offering.
4. Hiring additional personnel as transitioning to PSS requires companies to acquire new capabilities, knowledge, and expertise; for example, experts in managing contracts.
5. Cultivate long-term relationships with customers and other actors in the supply chain. Build long-term relations with customers through multiple touchpoints and leveraging customer feedback. Companies can partner with other actors to tap into complementary skills, knowledge, networks, and risk sharing.
6. Horizontal integration is aligning business strategies with other companies at the same supply or value chain level. This strategy combines expertise and acquiring capabilities, fostering collaboration and knowledge sharing to produce specialized solutions and create a one-stop shop for customers' needs.
7. Vertical integration is aligning business strategies with other supply or value chain companies. This strategy results in benefits such as increased control over the supply chain, cost savings and improved operational efficiencies, enhanced innovation and customization capabilities, and greater flexibility and agility.
8. Companies can use the knowledge and experience of other sectors, such as manufacturing companies. PSS's knowledge and awareness levels differ between the two industries, as the manufacturing companies have more experience with PSS.
9. Companies can utilize learning-by-doing through small-scale experimentation and adaptation to gain experience and improve. Companies must experiment, adapt, and improve as they progress because it is impossible to predict every outcome.

7.2 Recommendations for Practice

Companies offering PSS in the building sector should integrate tangible products, intangible services, networks of actors, and supporting infrastructure for successful adoption. Additionally, they should prioritize sustainability and circularity by incorporating sustainability and circularity principles in PSS offerings to minimize waste and promote resource efficiency. Therefore, it is necessary to understand the distinction between PSS focused on long-term relationships and those incorporating circularity and sustainability and actively embracing circularity concepts and sustainability factors.

Companies implementing PSS in the building sector can begin with an experimental phase to develop expertise, understand market dynamics, and refine offerings. The barriers identified in this study support companies to plan for potential challenges and focus on mitigating them. The circularity and sustainability aspects of PSS can help overcome financial barriers and funding challenges, making businesses in the building sector more attractive to investors and financial institutions while meeting customer demands. They can also serve as crucial drivers for justifying the transition.

This study serves as a guide for companies implementing PSS in the building sector. Companies can overcome challenges and increase their likelihood of successful PSS implementation by assessing the relevance of identified barriers within their specific context and utilizing the recommended solutions. The matrix diagram, a visual tool provided in this study, helps categorize barriers and map potential solutions, allowing companies to allocate

resources efficiently and address specific challenges. For example, vertical integration is an effective solution that addresses various supply chain barriers, while effective leadership plays a crucial role in tackling organizational barriers across the board.

In conclusion, companies implementing PSS in the building sector should integrate tangible products, intangible services, networks, and infrastructure while prioritizing sustainability and circularity. Understanding the distinction between relationship-focused PSS and those incorporating circularity and sustainability is crucial. An experimental phase helps develop expertise and refine offerings while addressing identified barriers. The matrix diagram aids in categorizing barriers and mapping solutions.

7.3 Recommendation for Further Research

Further research can explore PSS in the building sector from the customers' perspective, including their perception, attitude, and behaviors toward adopting PSS. The study could provide companies with significant insights into consumer preferences, requirements, and expectations, allowing them to understand better how to tailor their product-service offering to meet customer demands.

Studies can also focus exclusively on each category of barriers identified and undertake more in-depth research on the specific type of barriers and their potential solutions. For example, they can investigate technological barriers such as a lack of appropriate technology, design challenges to create durable products, and a lack of digitally-enabled services that companies face when implementing PSS in the building sector. Such a study can help companies to understand the technical challenges and potential of PSS BMs.

Additionally, future research can use case studies and empirical data to examine and validate the barriers and solutions found in this study. It could include doing qualitative or quantitative research to collect real-world data from companies in the building industry that have sought to adopt PSS and evaluating the findings to get practical insights into the effectiveness of different solutions in overcoming the barriers.

Furthermore, future research can concentrate on specific building systems or products, such as internal partition wall systems for residential and non-residential buildings, and investigate the possible barriers and solutions. The study may lead to a more technical understanding of the barriers and possibilities of deploying PSS in specific contexts and assisting companies operating in those product markets.

By addressing these research recommendations, future studies contribute to a better understanding of how companies can overcome the barriers of PSS BMs in the building sector and provide practical insights for companies looking to adopt or improve PSS offerings in their businesses.

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Appendices

Appendix I – Search Terms and Criteria

Keywords used for the search: Product service system, circular economy, circularity, sustain, develop, build, construct, residential, non-residential, barrier, enabler, and business model.

Scopus

Search date: 08 November 2022

The exact search term used: “Product service system” AND (“circular economy” OR circularity OR sustain*) AND (develop* OR build* OR construct* OR residential OR “non-residential”) AND (barrier* OR enabl* OR “business model”)

Result: 397 studies

Limitations applied as filters:

Document: Any type

Search area: TITLE-ABS-KEY

Language: English only

Date: documents after 2010

The total number of studies was 379 without including the time limitation; therefore, most of the studies are after 2010.

The search term from the advanced query of Scopus with filters applied – **Final results 367**

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TITLE-ABS-KEY ( "Product service system" AND ( "circular economy" OR circularity OR sustain* ) AND ( develop* OR build* OR construct* OR residential OR "non-residential" ) AND ( barrier* OR enabl* OR "business model" ) ) AND PUBYEAR > 2009 AND PUBYEAR < 2023 AND ( LIMIT-TO ( LANGUAGE, "English" ) )
```

Google Scholar

Search date: 08 November 2022

The exact search term used: “Product service system” AND “circular economy” OR circularity OR sustain* AND develop* OR build* OR construct* AND residential OR “non-residential” AND barrier* OR enabl* AND “business model”

Result: 415 Studies

Limitations applied as filters:

Document: Any type

Search area: Anywhere

Language: English only

Date: documents after 2010

The total number of studies was 415 without including the time limitation, again emphasizing that most of the studies are after 2010.

Final Result: 400 Studies

Studies included from citation searching -7 Studies

A total of 774 (=367+400+7) studies were considered, from which 45 were included in the review.

Appendix II – Interview Protocol

Graduation Project
10/01/2023

Interview Protocol
Institution: Delft University of Technology
Interviewer: Khesraw Shinwari

Interview

Part 1: Introduction *(10 minutes)*

Questions

Part 2: product-service system (PSS) *(20 minutes)*

1. Does your company or the organizations you work with provide a product-plus service or product-service system?
2. What specific product plus service or PSS does your organization offer?
3. Why does your organization offer these products plus services or PSS?
4. Is there any plan/room to increase your company's efforts in offering PSS?
5. What are the reasons you are not offering PSS?

Part 3: PSS barriers and enablers *(20 minutes)*

6. What are the barriers that your organization is facing in applying PSS?
7. In your opinion, which of the mentioned barriers is more critical to your organization and why?
8. Which barriers do you think your organization or company could manage and mitigate, and which cannot?
9. What are the potential solutions or enablers to overcome the barriers you think your organization could control?

Part 3: wrap up and conclusion *(10 minutes)*

10. Is there anything you want to discuss that I did not ask, or do you have any recommendations related to the topic we discussed?

Appendix III – Informed Consent Form

Explicit Consent Points

| PLEASE TICK THE APPROPRIATE BOXES | Yes | No |
|--|--------------------------|--------------------------|
| A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS, AND VOLUNTARY PARTICIPATION | | |
| 1. I have read and understood the study information dated [01/02/2023], or it has been read to me. I have been able to ask questions about the study, and my questions have been answered to my satisfaction. | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. I consent voluntarily to participate in this study and understand that I can refuse to answer questions and withdraw from the study at any time without having to give a reason. | <input type="checkbox"/> | <input type="checkbox"/> |
| 3. I understand that taking part in the study involves: Recording through the researcher’s cell phone and/or Microsoft Teams, which will be stored on a personal computer for transcribing, after which the recording will be deleted. | <input type="checkbox"/> | <input type="checkbox"/> |
| 4. I understand that the study will end on 04/30/2023. | | |
| B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION) | | |
| 5. I understand that the following steps will be taken to minimize the threat of a data breach and protect my identity in the event of such a breach. a) The researcher will anonymize all data collected during the interview b) The collected data will only be shared with the graduation committee after it has been anonymized and deemed untraceable to a specific person. | <input type="checkbox"/> | <input type="checkbox"/> |
| 6. I understand that personal information collected about me that can identify me, such as name, position, and organization, will not be shared beyond the study team. | <input type="checkbox"/> | <input type="checkbox"/> |
| 7. I understand that the (identifiable) personal data I provide will be destroyed by the end of the study, April 30 th 2023. | <input type="checkbox"/> | <input type="checkbox"/> |
| C: RESEARCH PUBLICATION, DISSEMINATION, AND APPLICATION | | |
| 8. I understand that after the research study, the de-identified information I provide will be used for the master’s thesis report, which will be publically available on the TU delft repository. | <input type="checkbox"/> | <input type="checkbox"/> |
| 9. I agree that my responses, views, or other input can be quoted anonymously in research outputs. | <input type="checkbox"/> | <input type="checkbox"/> |

Signatures

Name of participant

Signature

Date (DD/MM/YYYY)

[Add legal representative and/or amend text for assent where participants cannot give consent as applicable]

As a legal representative, I have witnessed the accurate reading of the consent form with the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of participant

Signature

Date (DD/MM/YYYY)

As a researcher, I have accurately read the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

Khesraw Shinwari

01/02/2023

Name of participant

Signature

Date (DD/MM/YYYY)

Study contact details for further information:

Khesraw Shinwari

Phone :

K.Shinwari@student.tudelft.nl,