TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
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ESTONIAN ACADEMY OF ARTS
FACULTY OF DESIGN

MSc. Design and Technology Futures

ENHANCING THE PRODUCT-SERVICE SYSTEMS APPROACH FOR BUILDINGS THROUGH A MULTICASE STUDY OF TEMPORARY MODULAR SOLUTIONS

TOOTE-TEENUSE SÜSTEEMSE KÄSITLUSE EDENDAMINE HOONETE JAOKS AJUTISTE MOODULLAHENDUSTE JUHTUMIUURINGUTE KAUDU

MASTER THESIS

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Tallinn 2024

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Enhancing the product-service systems approach for buildings through a multicase study of temporary modular solutions

supervised by **Kätlin Kangur, Christian Thuesen, Julia Köhler, Janno Nõu**

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THESIS TASK

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Thesis topic:
Enhancing the product-service systems approach for buildings through a multicase study of temporary modular solutions

Toote-teenuse süsteemse käsitluse edendamine hoonete jaoks ajutiste moodullahenduste juhtumiuuringute kaudu

Thesis main objectives:
1. Investigate the adverse effects of adopting PSS in buildings on the example of temporary modular buildings. This includes identifying areas for companies so they can successfully determine the areas in which effects may arise.
2. Gain direct insights from companies about how they are using PSS and the adverse effects and circularity outcomes they recognize it causes. This should be done by interviewing several subject matter experts.
3. Develop an approach to assist companies in evaluating and managing the effects, including both intended and unintended outcomes, of PSS adoption. The objective of providing this practical holistic approach for companies is to enhance informed decision-making processes related to the design, implementation, and management of PSS initiatives, with a focus on holistic and obtaining circular approaches.

Thesis tasks and time schedule:

No	**Task description**	**Deadline**
1.	Desktop research	15.02.2024
2.	Design Research, Interviews	01.04.2024
3.	Design Concept, Workshops	10.05.2024

Language: English **Deadline for submission of thesis**: “20”05.2024a

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ABSTRACT

The building sector's reliance on traditional practices poses a significant sustainability challenge. Recognizing this challenge, Product-Service Systems (PSS) models emerge as a promising avenue to foster sustainable practices. PSS models, by extending value beyond traditional product sales and integrating services throughout a product's lifecycle, offer a strategic pathway for embedding sustainability into the built environment. However, realizing the full potential of PSS requires a comprehensive understanding of its multifaceted dimensions, spanning economic, technological, legislative, environmental, social, and behavioral aspects, to mitigate unintended consequences.

Through an explorative research approach, this study examines the diverse impacts of PSS adoption within the built environment through a Design Research Methodology alongside systems thinking, with a specific focus on modular temporary buildings as a case study. Employing a multi-case study methodology and systems thinking framework, the research explores the implications of PSS models, uncovering both benefits and unwanted outcomes in their implementation. This is done by semi-structured interviews with industry professionals and literature analysis of secondary data sources to provide valuable insights.

Central to this research is the development of an early-stage assessment tool tailored to the complexities of PSS adoption in the industry. This tool aims to support theoretical understanding and practical application, offering valuable insights to inform sustainable implementation strategies when little is known. To achieve this, the Helix Scope tool was created. Originating from the fundamental idea of providing support when little is known, the tool aims to reduce reliance on intuition and offer accessible guidance to companies with restricted resources. Developed through co-creation workshops with industry professionals, the Helix Scope tool assists companies in making the best possible decisions under constraints, thereby promoting sustainable practices in the built environment.

By highlighting the nuanced dynamics of PSS integration, this study contributes to advancing sustainable practices within the building sector and facilitating the transition towards more resilient and conscious decision-making.

Keywords: Master's thesis, Product-service systems, Systems thinking, Circular economy, Buildings

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

B2B - business-to-business

B2B2C - business-to-business-to-customer

CE – circular economy

CO_2 – carbon dioxide

C&D - construction and demolition

DS – descriptive study

DRM - Design Research Methodology

ESG - environmental, social, and governance

EU – European Union

LCA – life cycle assessment

PSS – product-service system

RE – rebound effect

S.PSS – sustainable product-service system

1. INTRODUCTION

The first chapter presents the background of the research (section 1.1). Subsequently, the research questions are formulated (section 1.2) and the Master of Science Thesis objectives are outlined (section 1.3). Finally, the structure of the work is described (section 1.4).

1.1. Background

Given the pressure posed by climate change and degradation of resources, there is rising pressure transition towards sustainable practices across all industries. With the European Commission constructed framework targeted at encouraging the growth of sustainability to tackle natural resource depletion, companies must set objectives to meet these objective (European Commission, 2015). Amongst others, construction (including buildings) and demolition are at the forefront (Llorente-González & Vence, 2019; European Commission, 2015), as around half of the resources are consumed by the built environment, encompassing buildings, roads, infrastructure, etc (Ellen Macarthur Foundation, n.d.(a)). Construction and building activities generate amongst others for instance over 35% of the total waste and contribute 5-12% to the EU's overall greenhouse gas (GHG) emissions through material extraction, manufacturing, construction, and renovation (European Commission, n.d.). The built environment is experiencing significant growth, which presents a challenge to the current building practices and raises concerns about the sustainability of linear models (Ellen Macarthur Foundation, n.d.(a)).

In response to these challenges, circularity-based models have emerged as an alternative to conventional linear practices across various sectors (Munaro et al., 2020). The core principles focus on closing the loop by reducing the consumption of materials and increasing the time the resources are being used during their life cycle. Ensuring the ongoing functionality and performance through regular upkeep or care, reuse or repurposing to extend their lifespan, in some cases disassembling a product, replacing worn-out or damaged components, rebuilding, and recycling to create something new thereby reducing the need for virgin materials and minimizing waste. Through restorative and regenerative design, products are preserved for longer, aligning with principles of sustainability (European Commission, n.d.; Ellen Macartur Foundation, 2013; Kirchherr et al., 2017; Zairul et al. 2018).

Product-service systems (PSS) have been seen as a promising alternative to sustaining such circularity in built environments (Ghafoor et al, 2023). PSS represents a strategic approach to innovative business models. This approach aims to move beyond simply selling products and instead create value by integrating services throughout a product's lifecycle, thus creating value beyond mere product sales. This shift aims to achieve business success that is not solely reliant on the volume of products sold (Goedkoop, 1999; Mont, 2004). While researchers have explored various aspects, such as the potential structure and advantages of PSS for models (Galle et al. 2019), the challenges like awareness, positioning, and operational questions associated with integrating PSS into the supply chain (Andersson & Lessing 2019), or the utilization of modular volumes (Cambier et al., 2021), the realization of these benefits relies on effective implementation. Neglecting to prioritize economic, environmental, and social dimensions equally in PSS implementation can lead to unintended outcomes (Ghafoor et al, 2023).

These unintended effects can stem from a various of factors, including individual actions and broader systemic factors, impacting areas like energy efficiency, economic growth, and environmental, social, and circular economy (Metic & Pigosso, 2022). However, within the built environment it is recognized that the challenges are even more complex, spanning economic, environmental, behavioral, societal, technological, and governmental dimensions (Pomponi & Moncaster, 2017). A comprehensive understanding of the multifaced impacts associated with PSS adoption regarding buildings has yet to be fully explained despite growing interest in PSS adoption, necessitating further research (Ghafoor et al., 2023).

Implementing PSS within the built environment presents a key challenge, as addressing potential adverse effects is essential. PSS can influence everything from the design of individual building components to the resource management of entire industrial parks and buildings, ultimately shaping the resource efficiency of entire cities across various dimensions (Pomponi & Moncaster, 2017). Therefore, embracing such an approach requires a holistic perspective (Yang & Xing, 2013; Iacovidou et al., 2021), especially in the context of buildings, which have historically been overlooked (Brady et al, 2005;

Ghafoor, 2023). This is especially crucial in the early stages, where changes are less costly (Schmidt et al., 2015) yet have significant influence (McAloone & Bey, 2009).

Early-stage approaches can aid companies in systematically harnessing the positive impacts of PSS while mitigating negative effects (Metic & Pigosso, 2022; Yang & Xing, 2013), especially when customized to suit practitioners' requirements (Becker et al., 2010) and embed sustainability principles (Pigosso et al., 2013). What frequently occurs during the initial stages is that practitioners heavily lean on their expertise and intuition instead of engaging in systematic planning. This often results in undetailed and ineffective planning, which fails to offer them effective guidance (Yang & Xing, 2013). Metic and Pigosso (2022) note that current ex-ante approaches predominantly focus additionally on the macro-level, with limited exploration of micro- and meso-level considerations.

However, when it comes to buildings, such approaches fall short of providing guidance on critical elements, given their long-term setup. Additional pressure arises for instance from the challenge of integrating PSS into the building of traditional models proves particularly challenging as owning has been seen as an investment, a cornerstone of security, and even a marker of social standing. These deeply rooted perceptions are further prevailing due to ingrained cultural attitudes and supportive policies (Cohen, 2021), which makes the move toward PSS might encounter additional resistance due to these established systems (Cambier et al., 2021).

1.2. Research questions

Building upon the identified challenges and opportunities associated with PSS implementation in the built environment, this explorative research delves deeper into two key questions:

> What are the key elements that companies must consider when designing product-service systems?

Additionally, the following sub-research question is presented:

> How to support companies with the adoption of product-service systems in the early design stages?

By investigating these questions and leveraging the cases of temporary modular buildings (hereafter referred to as "buildings"), this research aims to contribute to the identified problem space with understandings of the adverse outcomes of integrating PSS into buildings through literature and usage of MAXQDA thematical exploration. These key elements will provide companies with guidance for designing PSS for buildings that maximize the intended benefits, particularly during the early design stages. This is crucial as knowledge and resources are often most limited at this initial phase.

1.3. Objectives of the MSc Thesis

The objectives and deliverables of this MSc thesis are summarized in the following bullet points:

- Investigate the adverse effects of adopting PSS in buildings on the example of temporary modular buildings. This includes identifying areas for companies so they can successfully determine the areas in which effects may arise.
- Gain direct insights from companies about how they are using PSS and the adverse effects and circularity outcomes they recognize it causes. This should be done by interviewing several subject matter experts.
- Develop an approach to assist companies in evaluating and managing the effects, including both intended and unintended outcomes, of PSS adoption. The objective of providing this practical holistic approach for companies is to enhance informed decision-making processes related to the design, implementation, and management of PSS initiatives, with a focus on holistic and obtaining circular approaches.
    - Test the approach and its applicability with companies through co-creation workshops. The feedback gathered from these workshops will be utilized to refine and enhance the approach.

1.4. Chapter Overview

The thesis is presented in nine chapters, with a summary of the contents of each as follows:

Chapter 1: Introduces the thesis topic, research questions, and objectives of the work.
Chapter 2: Provides an overview of the research process and methodology used.
Chapter 3: Presents the theoretical background relevant to the thesis topic, considering the background the context of buildings.
Chapter 4: Focuses on the specific context of temporary modular buildings, highlighting where these buildings are operating. This chapter complements, rather than repeats, the content of Chapter 3.
Chapter 5: Presents the results and discussions that form the above chapters relevant to the design concept development.
Chapter 6: Focuses on the development of strategies needed to help companies identify and mitigate potential effects of adopting product-service systems and translates them into the design concept.
Chapter 7: Describes the refinement of the previously presented design concept based on feedback and further analysis.
Chapter 8: Discusses the uniqueness of the proposed solution, other existing solutions, and explores its limitations and potential future work.
Chapter 9-10: Draws the conclusions of the work both in English and Estonian, summarizing the findings and their implications.

Keywords: Master's thesis, Product-service systems, Systems thinking, Circular economy, Buildings

2. RESEARCH METHODOLOGY

This chapter presents an overview of the methodology used. The overarching approach leans on the Design Research Methodology (DRM) (Blessing & Chakrabarti, 2009) that has four phases: research clarification, descriptive study I (DS I), prescriptive study, and descriptive study II (DS II). The first phase lays the groundwork by establishing a broad understanding of the problem space and defining initial research goals. Subsequent phases build upon the previous, with each serving a distinct purpose (see Figure 1). The research context progressively narrows throughout the phases, leading, in this work, to a deeper understanding of PSS adoption in temporary modular buildings. This approach fosters a deep understanding of the problem while maintaining the flexibility to adapt the research strategy as new insights emerge.

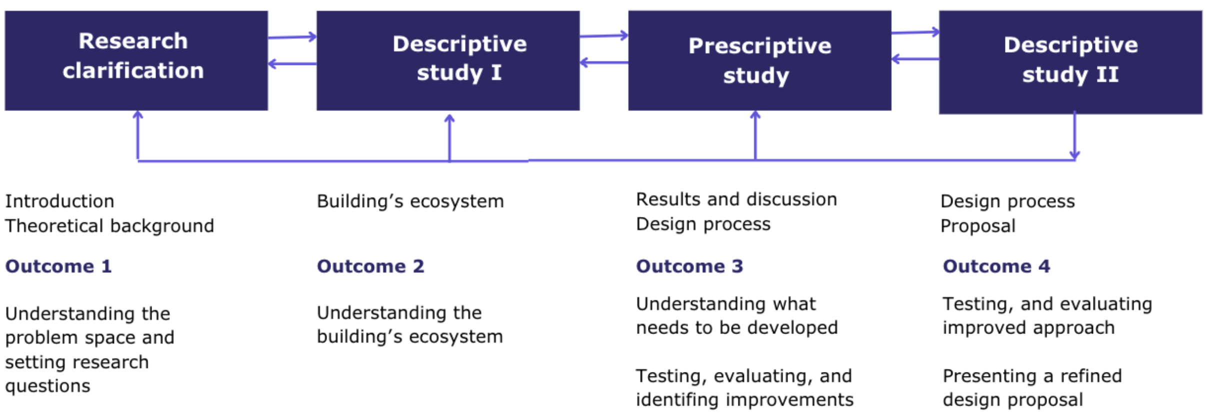

Figure 1: DRM framework. Source: Adapted from Blessing & Chakrabarti, 2009, inspiration from Harild & Gustafsson, 2021.

2.1. Research Clarification

In this clarification phase, the emphasis was set on refining and formulating research questions through literature. The objective was to gather supportive evidence, ensuring clear task identification and the relevance of the study. This phase provided the foundational framework for subsequently delineating the current situation, upon which further investigations were constructed (Blessing & Chakrabarti, 2009).

The literature review delved into the subject matter by utilizing specific keywords such as 'product-service system,' 'PSS,' 'servitization,' 'as-a-service,' 'integrated solutions,' along with terms relevant to buildings and modular construction. This process aimed to identify relevant information, providing further insight into the research and the formulation of semi-structured interview questions.

2.2. Descriptive study I

Equipped with a clear research questions(s), the DS I aimed to go deeper into the design process through building-specific literature. The goal was to uncover factors influencing task clarification and seek answers (Blessing & Chakrabarti, 2009).

To gather in-depth information from various industry professionals and relevant information about the current situation, semi-structured interviews were utilized, where participants shared their knowledge and insights. This approach involved using a set of predetermined questions (see Appendix 1) while also allowing the flexibility for the interviewer to delve deeper into participants' experiences. As an exploratory study, semi-structured interviews enabled participants to flexibly share their unique perspectives, offering valuable insights beyond the initial questions (Adeoye-Olatunde & Olenik, 2021). Interviews were conducted continuously, allowing for ongoing discovery throughout the research process and refined interviews with insights from already finished interviews. Table 1 provides an overview of the conducted interviews:

Table 1: List of interviews. Source: Author

Interviewee	Position	Company	Location	Duration (minutes)	Date (2024)
Y1	Production manager	Modular houses with expert consultation	Latvia	71	05.03
Y2	Sustainability Lead (Design & Engineering)	Modular emergency/ temporary housing	UK	62	05.03
Y3	Baltics Quality Manager	Machinery (including heating),	Estonia	78	06.03

		Modular temporary buildings			
Y4	Manager, co-founder	Modular Shed-as-a-Service	Denmark	58	12.03
Y5	Head of sustainability	Modular emergency/ temporary housing	UK	36	14.03
Y6	Climate programme manager	Modular emergency/ temporary housing	UK	56	19.03
Y7	Manager Sustainability, Social and Customer Support	Wood production	Finland	64	22.03
Y8	Sustainability manager and Management engineer, Service	Modular emergency/ temporary housing	Sweden	59	26.03

The participants for the interviews were picked based on two key factors: region and area of expertise. Due to limited in dept access to specific companies, the research prioritized identifying multiple cases with similar characteristics within Europe’s continent. To incorporate broader perspectives, Gharoof's (2023) definition was utilized, which centers on space, material, and electricity as primary areas of focus currently in buildings and housing. This is why Y3 and Y7 were included as they had insights into the material or machinery/electricity side due to their other business unit.

The interest pool of people was contacted on LinkedIn and in some cases, if possible, through a work email. This yielded five respondents from a targeted pool of 50 potential participants. Acknowledging the small readiness, further efforts were made to broaden the participant pool. Additionally, sustainability consultants across Europe, known to collaborate with companies relevant to the researched topic, were approached. However, this strategy did not generate any additional responses. Through recommendations, the list of interviewees grew to eight that are within the temporary modular building sector.

Companies willing to share their insights are predominantly linked to the buildings through modularity, and use of circularity principles, with few exceptions (Y3 and Y7). However, all the companies have implemented parts into their business models that can be classified as PSS, operating mainly in a business-to-business-to-customer (B2B2C) environment, which adds a multilevel relationship aspect.

Qualitative data analysis was conducted using MAXQDA software. A thematic analysis approach was employed, focusing on identifying and exploring recurring themes and patterns within the interview transcripts (Adeoye-Olatunde & Olenik, 2021). Transcripts are not provided in this published thesis due to confidentiality but were handled for analysis purposes.

2.3. Prescriptive study

Drawing from the insights gained in DS I, a vision for an initial design concept was formulated. The first version of the tool originated in this prescriptive study and was described in Section 6. This vision was shaped by a deeper understanding of the interconnected factors within the building environment, and a refined description of a potential design process (desired situation) (Blessing & Chakrabarti, 2009).

The designs' effectiveness in achieving the desired outcomes remained here untested. Given the numerous assumptions underlying the desired situation and the development of the tool, further investigation was deemed necessary.

2.4. Descriptive study II

The final phase aimed to test and evaluate the developed design concept, measure its success, and identify improvement opportunities. The prescriptive study and DS II were conducted in an iterative loop. This meant phases were carried out simultaneously – first to develop a preliminary version of the method and then again to refine and enhance it based on the learnings from the initial evaluation and additional materials.

This stage focused on assessing the support tool's effectiveness in achieving the desired design process outlined earlier. Two different types of studies were conducted in all the workshops (Blessing & Chakrabarti, 2009):

- The applicability aspect assesses how effectively the tool integrates into existing workflows and contributes to the evaluation process.
- The usefulness component examines the tool's capacity to fulfill predefined criteria, aiming to understand its impact on addressing challenges encountered by companies.

Based on these goals similarly to a semi-structured interviews questions were combined (see Appendix 2) Semi-structured guide was Consequently, the tool underwent multiple testing in four workshops (see Table 2) involving two different companies—one possessing three decades of industry experience (W1 and W3), while the other was in its early phase (W2 and W4).

Table 2: List of workshops. Source: Author

Workshop	Position	Company	Location	Duration (minutes)	Date (2024)
W1:Y8	Sustainability manager and management engineer, services	Modular emergency/ temporary housing	Sweden	69	11.04
W2:Y4	Manager, co-founder	Modular shed-as-a-service	Denmark	67	07.04
W3:Y8	Sustainability manager and management engineer, services	Modular emergency/ temporary housing	Sweden	47	23.04
W4:Y4	Manager, co-founder	Modular shed-as-a-service	Denmark	81	26.04

During the workshop, given the multifaceted nature of the tool, a single PSS element—either product or service—was selected based on each participant's specialty to assess its functionality. A cognitive walkthrough was used to facilitate discussions about the tool's comprehension while the participant was performing tasks with the tool's prototype. This enabled within a short period to engage the user directly to learn the tool's functionalities rather than spending time reading the instructions (Interaction Design Foundation, 2016a). Moreover, participants were encouraged to articulate their thoughts aloud while engaging with the tool, utilizing a thinking aloud protocol (Nielsen, 2012) to gain insights into the improvements and reiterated design concepts. Essentially these steps facilitated co-creation, meaning collaboration with stakeholders that enables gaining insights for the design process (Interaction Design Foundation 2016).

3. THEORETICAL BACKGROUND

This chapter examines the literature to give an overview of the context of the research area. As mentioned above PSS is gaining traction as a promising approach to achieve circularity and sustainability within the built environment, also amongst temporary modular buildings (Ghafoor et al, 2023). This approach goes beyond traditional product ownership, integrating services to deliver value, minimize environmental impact, and potentially even reduce resource consumption (Kirchherr et al., 2017). Understanding how the core elements of a PSS - product, service, infrastructure, and actor network - interact and influence sustainability is crucial (Mont, 2004). Such an approach acknowledges the interconnectedness of various elements and ensures that PSS models are designed and implemented with an understanding of their multifaceted dynamics. Achieving Sustainable Product-Service Systems (S.PSS) requires a balanced approach between the elements, considering both positive impacts and potential drawbacks across relevant dimensions (Cellucci, 2021).

Therefore, the chapter starts with an exploration into the definition of PSS (section 3.1.1), the discussion then delves into its constituent elements (section 3.1.2). Moreover, it scrutinizes how the balance among these elements drives the concept of S.PSS and its positive impacts (section 3.2-3.2.1), while also addressing the consequences of an imbalance between these elements and sustainability dimensions. Therefore, the chapter further elaborates on the barriers (3.2.2), explores the application of systems thinking principles, and introduces external legislative factors that influence the promotion of such models (section 3.3), specifically within the built environment, with a primary focus on buildings.

3.1. Product-Service System

A PSS combines products and services to provide value to customers while prioritizing sustainability and sets resource decoupling as a focal point (Mont, 2004).

3.1.1. PSS definition and typology

The PSS concept emerged as a strategy to seamlessly integrate both products and services in ways that effectively deliver the intended value for customers (Goedkoop, 1999). However, as the model found diverse applications across various fields, interpretations diverged. The concept still lacks a single, universally recognized definition reflecting the concept's ongoing evolution (Li et al., 2020). However, it has been observed that PSS prioritizes outcomes (Leoni & Poggesi 2017), thereby acknowledging broader sustainability objectives as a crucial component. Monts‘ (2004, 140) definition exemplifies this evolution, describing PSS as a "system of products, services, networks of actors and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and has a lower environmental impact than traditional business models". By retaining ownership of products within a PSS model, companies have stronger incentives to design durable and repairable products. This shift naturally pushes companies to minimize resource use throughout the product lifecycle as the models often incorporate closed-loop systems and offer services that prolong product use (Stahel, 1997; Mont 2004).

Tukker (2004) provides valuable insights into the different manifestations of PSS and their potential sustainability impacts. His typology categorizes value creation from purely tangible to purely intangible into three main categories that in return are divided into eight subcategories (see Figure 2):

- **Product-oriented PSS** prioritizes selling the physical product extending the value proposition by incorporating additional services throughout the product's lifecycle. These services can range from maintenance contracts and financing schemes to take-back agreements for responsible end-of-life management. Even advice on maximizing product effectiveness can be considered a form of this category.
- **Use-oriented PSS provides** access to a product while maintaining ownership. Value is offered through temporary use of the product: leasing, renting, sharing and pooling. The service provider retains ownership and responsibility for the product's maintenance, repair, and control. While in some cases, only one user has access at a time (leasing), other formats allow access for multiple users, either sequentially or simultaneously (renting and sharing/pooling).
- **Performance-oriented PSS** focuses on delivering value through specific outcome, not the product itself. In some cases, the service provider may outsource activities to ensure that the desired outcome is achieved and in others "pay-per-service" models, where users pay based on usage or functional results agreements, where

the provider guarantees a specific outcome. In latter the provider takes full responsibility for choosing the most efficient and suitable methods to achieve the agreed-upon outcome.

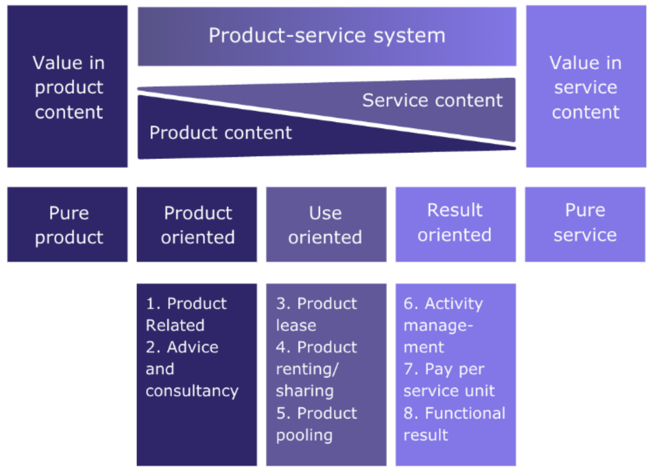

Figure 2: Main and subcategories of PSS. Source: Tukker, 2004

With the expansion of services, there is a corresponding increase in the potential for sustainability. However, the degree of sustainability improvement varies depending on the nature of the services provided within the framework of PSS (Tukker, 2004). In product-oriented services, where the focus lies on enhancing maintenance, only minor sustainability enhancements can be expected. Conversely, use-oriented services offer a promise of greater sustainability by emphasizing higher product usage intensity, thereby reducing the overall quantity of products required. Lastly, the result-oriented approach, characterized by the interconnected networks and focus on the outcomes, holds the greatest potential for sustainability. This typology indicates interplay among products, services, networks, and value generation within PSS (Tukker, 2004, 2015).

3.1.2. PSS elements

Mont (2004) established a framework with elements and feasibility criteria foundational for the successful implementation of the PSS and must be analyzed for their significance in achieving the set goals. At the core of a PSS lies the organization implementing the model that must consider four key elements equally important to deliver an intended value:

- **Product** is a tangible element that oftentimes needs adjustments to support the system's other elements. When ownership is shifted to service models, it opens the possibility of redesigning products to facilitate their efficiency and extend their lifespan. With that product component of PSS extends beyond its physical form; it serves as a crucial element that can be optimized for durability, multi-user functionality, and resource efficiency.

- **Service** is an intangible add-on to the product keeping in mind the environmental considerations and customer satisfaction. With the component, the focus is shifting away from selling the product volume to product use to access. By integrating various services, the outcome of a product can be enhanced.
- **Infrastructure** is a complex network, encompassing both public and private, supporting and shaping the consumption patterns and enabling the delivery of PSS. Investment in infrastructure that supports resource efficiency and waste management is imperative for the success of PSS initiatives because a lack of it can lead to less sustainable choices. Infrastructure also includes roads, different other collection systems (take-back systems, etc.), and communication networks.
- **Actor network** is a group of partners working together to make sure all the functionalities of a PSS will be delivered. For the best system's efficiency, functions must be delivered by experts.

Instead of merely outlining each element, it's crucial to examine their connectedness, implications, and potential impacts, particularly concerning their role in sustainable design (see Figure 3). Understanding why each element is vital within their context as it allows aligning them with sustainability objectives. This approach ensures that the elements are prioritized based on their potential to have the greatest influence and contribute most significantly to achieving our sustainability goals (Mont, 2004).

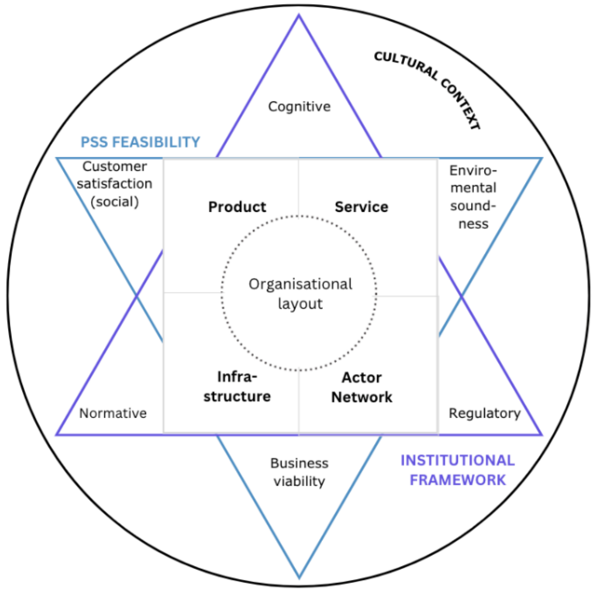

Figure 3: Framework for the successful implementation of PSS (Mont, 2004)

Traditionally, business viability depends on factors like profitability and competitiveness. However, it is intricately linked with customer satisfaction, as contented users are more inclined to recommend the system to others, increasing competitiveness. The PSS users may initially experience uncertainties due to the unfamiliar consumption model raising the need for providers to actively involve users and educate them about the system's benefits. At this point, it is still not sure if the offering is more sustainable than the traditional model. After the product is on the market, viability can be assessed. This encompasses the evaluation of environmental soundness criteria, thereby heightening the significance of thorough preplanning (Mont, 2004).

Achieving success with the PSS model goes beyond mere operational considerations. It relies on a profound comprehension of the cultural context in which elements are affected by a complex ecosystem where various elements interact. These elements include the normative structure, a set of collective values and regulations that change the individuals' sense of self, perception of the surroundings, and daily decision-making processes (Mont, 2004). Here consumption patterns like materialism and ownership have a significant role (Cohen, 2021). Another key element is the cognitive structure which refers to a learning process that helps people to make sense of the world and make decisions. This is heavily influenced by cultural norms; people's understanding comes from the group that operates in an ecosystem within the regulatory structure set to regulate users' behavior (Mont, 2004). Recognizing and navigating the intricate interplay between these elements is paramount for designing and implementing PSS solutions that contribute to the advancement of S.PPS design (Vezzoli et al 2021).

3.2. Sustainable PSS

As briefly mentioned before, the level of integration between products and services within a PSS impacts its circularity potential. The higher the level of integration creates the more opportunities to improve sustainability (Tukker, 2015; Kjaer et al., 2018; Cellucci, 2021). This alignment with sustainability principles is also emphasized by Lozano (2008), who highlights how PSS encourages companies to consider social and environmental factors alongside profit. Pomponi and Moncaster (2017) suggest that companies operating within the built environment need to develop a more comprehensive understanding of their surrounding context and consider governmental, technological, and behavioral dimensions as well. Hence, for companies to fully benefit from PSS, all dimensions of sustainability must be prioritized to "…offer model providing an integrated mix of products and services that are together able to fulfill 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 ownership of the product/s and/or its life cycle responsibilities remain by the provider/s, so that the economic interest of the providers continuously seek new environmentally and/or socioethically beneficial solutions" (Vezzoli et al 2021, p. 2). This holistic perspective not only enhances the circularity potential of PSS but also promotes long-term benefits. As such, the implementation of S.PSS represents a promising avenue for organizations seeking to achieve sustainable value creation and address contemporary societal challenges. By prioritizing sustainability across all facets of PSS implementation, organizations can foster resilience, innovation, and inclusive growth (Cellucci, 2021).

This section begins by exploring the benefits of PSS when given equal consideration to the environmental, social, and economic aspects of sustainability. While striving for balance can lead to resource efficiency, societal well-being, and economic resilience amongst others, neglecting any dimension poses the risk of unintended consequences that could undermine PSS's sustainability goals (Metic & Pigosso, 2022). Therefore, the benefits that come with strategic planning will be explored in the next section.

3.2.1. PSS benefits

By retaining ownership, S.PSS providers are incentivized to design products for a longer lifespan, prioritizing durability, repairability, and upgradability (Vezzoli et al., 2021). This reduces the need for frequent replacements, resulting in minimized resource consumption, overall waste generation, and the use of virgin materials (Vezzoli et al., 2021; Giglio & Codispoti, 2021). With the decrease in raw material extraction and processing PSS reduces the potential need for harmful chemicals and toxins (Heisel et al., 2019).

Designing products for intensive use and longevity with adaptable components such as modules enables PSS to evolve and adapt to changing lifestyles, needs, and external factors over time (Geldermans et al, 2019; Vezzoli et al., 2021; Cambier et al., 2021). This further incentivizes companies to design resource-efficient products that are suitable for multiple relocations. This might involve features such as lightweight materials and designs that facilitate repairs and upgrades (Huovila et al., 2019) or partnering with demolition contractors to identify and source reusable secondary materials for product refurbishment or upcycling initiatives (Çetin et al., 2021). PSS are also increasingly incorporating biomimicry solutions. These include rain and wastewater treatment inspired by natural filtration systems; biogas generation and in-vessel composting that mimic decomposition processes; thermal and photovoltaic systems that capture the sun's energy like plants; green walls that act as living air purifiers optimizing further the life cycle management. (Bertino et al., 2018).

Traditional product ownership often involves high upfront costs, making them inaccessible to certain segments of society. PSS models typically break down payments into more manageable installments (Huovila et al., 2019), increasing affordability for low- and middle-income groups who can now access products that might have been out of reach previously (Vezzoli et al., 2021). This further encourages changes in consumption habits (Eikelenboom et al., 2021) by incorporating maintenance and repair services within the service offering. It can lessen the burden of unexpected repair costs, further enhancing financial security for both users and companies (Vezzoli et al. 2021).

While users gain a holistic offering with a lower total cost of ownership (van Stijn & Gruis, 2019), the companies can foster long-term customer relationships throughout the product lifecycle. This focus on customer retention helps build loyalty and encourages repetitive business, leading to a more stable and predictable income. As companies can generate predictable income for example through subscription or pay-per-use models (Vezzoli et al., 2021), companies are more likely to explore and invest in innovative service offerings (Liedtke et al., 2015). These new offerings might leverage data-driven insights, integrate digital technologies, or even incorporate more widely the above-mentioned nature-based solutions (van Stijn & Gruis, 2019). By offering innovative service models alongside the product, companies can improve their competitiveness and eventually differentiate themselves in the saturated market via sharing value with stakeholders (Vezzoli et al., 2021).

PSS can contribute to an all-inclusive environment for the stakeholders within the ecosystem as it emphasizes fair labor practices and healthy working conditions throughout the product lifecycle (Murray et al., 2015). Additionally, PSS models promote for instance societal well-being by addressing needs such as safety (PwC, n.d.), healthy indoor climate (Oorschot & Asselbergs, 2021). By involving communities throughout the design process, from vision-setting to implementation and evaluation, PSS solutions can be tailored to better address needs but also empowers residents to become agents of change (Eikelenboom et al., 2021).

Community engagement has the potential to educate residents about business creation, potentially stimulating the local job market, particularly in underserved communities. Studies suggest a correlation between active community participation and an increased sense of responsibility for solutions (Criollo & Villacis, 2020; Mazur 2021), which is why building trust and consumer awareness remains crucial for the widespread adoption of PSS models and the realization of the benefits in all the dimensions of sustainability (Vezzoli et al. 2021).

3.2.2. Barriers, the unintended outcomes and their typology

While PSS holds promise for sustainability enhancement of buildings, its effectiveness depends on the strategies and typology implemented (Tukker, 2015). The benefits, however, may not always materialize as intended. In fact, studies have shown that efficiency-focused solutions like PSS do lead to unintended outcomes due to behavioral and systemic responses, increasing the importance of why such outcomes most also be in focus (Metic & Pigosso, 2022).

The unintended outcomes also known as rebound effects (RE) have a long history, dating back to 1865 when a counterintuitive phenomenon was observed that increased efficiency in coal use did not lead to less consumption (Jevons, 1865). Instead, cheaper coal led to more consumption potentially negating the initial intended environmental benefits. Khazzoom further explored this paradox in the field of energy efficiency. His research demonstrated that efficiency gains can have the unintended outcomes of reducing the implicit price of energy services. Since the demand for energy services typically exhibits negative price elasticity, the price reduction can lead to increased consumption, potentially offsetting some of the initial efficiency benefits. Brookes added a macroeconomic viewpoint discovering a synergy between RE and the environmental movement, particularly regarding greenhouse gas (GHG) emissions (Saunders, 1992).

Over the years scholars have expanded the term to all dimensions of sustainability defining RE as situations (Metic & Pigosso, 2022, p. 1) “where circular activities do not succeed in outpacing increases in consumption, causing increased production levels and reducing the expected decoupling benefits”. Focusing solely on one dimension, for instance, economic benefits through increased efficiency, can lead to unintended outcomes in other areas, like neglecting social impacts on local communities from waste management facilities. Therefore, a holistic approach that considers all dimensions to understand the occurrence of RE is a key (Geissdoerfer et al., 2017).

A systematic literature review by Metic & Pigosso (2022) mapped five areas where such drawbacks are prone to occur. The first three categories delve into how enhanced efficiency can influence consumption levels and environmental outcomes. Lower prices resulting from increased efficiency often stimulate heightened consumption, as consumers gravitate towards more efficient technologies, potentially offsetting the intended benefits. Moreover, economic expansion driven by efficiency gains may lead to a growth in resource consumption alongside economic activity, contributing to environmental rebound effects through heightened resource extraction. Social rebound effects further underscore the complex dynamics between resource efficiency and sustainability dimensions, as positive outcomes like job creation and empowered communities coexist with negative impacts such as pollution and social disruption from waste management facilities and reverse logistic systems. Additionally, circular rebound effects describe scenarios where strategies like product life extension or increased use of recycled materials may impact the realization of positive outcomes. A narrow initial assessment might suggest environmental benefits, but a more holistic approach considering the entire supply chain (e.g., cardon dioxide (CO_2) emissions) might reveal that reuse is not the best option in some specific cases. In conclusion, these categories emphasize the need to consider not just individual unit efficiency but also potential changes in other factors or even new functionalities.

In broad, all these RE can be categorized as direct, indirect, economy-wide and transformational. Direct RE linked to the phenomenon where the increase in consumption outweighs the initially planned effects. For example, leaving lights on unnecessarily can lead to increased energy consumption. This can then in return trigger indirect rebound effects, wherein consumers may wish to spend more on other elements, known as the income effect. Another form of indirect rebound effect is the substitution effect, where the lower price of a new product may increase the desire to use it more, not just due to increased income but also because it feels more appealing than other goods on a psychological level. On an economy-wide scale, REs is related to the improved social environment brought about by a product, which may lead to increased efficiency in other areas, thereby affecting prices and consumption patterns once again. Transformational changes are closely related to the economy-wide category. These are the changes that initiate shifts across such as social norms, legislation, and other societal elements (Greening et al. 2000).

Although RE are frequently perceived negatively, it's essential to acknowledge that they can also produce positive outcomes depending on the specific context and manner of implementation (Hertwich, 2005). As a result, in striving for a neutral stance, these adverse effects are labeled in this work as "unwanted outcomes" and are explored based on their impacts from multiple perspectives, encompassing effectiveness, economic, environmental, social, circular, or other viewpoints. These consequences often arise from deliberate decisions aimed at altering PSS, and the focus lies in estimating their direct or indirect effects across different levels (micro, meso, and macro) (Pomponi and Moncaster, 2017). Addressing these outcomes is crucial as it becomes apparent that negative effects may overshadow the positives, exerting a pervasive influence that can undermine intended outcomes (Jevons, 1865; Saunders, 1992; Metic & Pigosso, 2022) as highlighted through various researchers works.

3.3. Systems thinking

Barry Richmond was among the first to articulate the principles of systems thinking as an analytical approach that acknowledges the interconnectedness between behaviors and other elements within a system. His work emphasized more the importance of delving into behavior (Richmond, 1994). Peter Senge instead defined systems thinking as a disciplined intuitive approach aimed at perceiving wholes, interrelationships, and patterns of change within such systems (Senge 1990 as cited in Arnold & Wade 2015). Building upon these foundational ideas, Meadows (2008) identified three key components of systems thinking: elements, interconnections, and purpose. Elements represent the constituent characteristics of a system, while interconnections signify the dynamic relationships among these elements. The overarching purpose or function of the system provides an opportunity to comprehend its behavior and guide for effective intervention.

When applied to a PSS, systems thinking can be beneficial, especially in complex environments like the built environment, where there are many elements that affect each other (Tukker, 2004; Mont, 2004; Pomponi & Moncaster, 2017). By comprehending the characteristics and context of the system, it becomes easier to grasp the potential effect areas for improvement. Systems thinking, described as a framework adept at effectively addressing intricate situations marked by uncertainty (Grohs et al., 2018), allows examination of how such various elements within the system interact. This approach enables the navigation of complexity (Cezarino & Beltrán, 2009) as it views the ecosystem through a lens that analyses the dynamic interplay between people, products, services, and their surrounding environment (Forlizzi, 2008). In essence, systems thinking, as defined by Senge (1990, p. 68, as cited in Forlizzi 2013), provides a holistic approach to understanding the broader impacts of design choices through understanding the system (Forlizzi 2013).

Considering these challenges, the application of systems thinking becomes imperative in addressing the complexities inherent in service-based systems within the built environment. As designers acknowledge the necessity of transitioning towards service-based systems to promote sustainability (Manzini, 2011 as cited in Forlizzi, 2013; Ghafoor et al., 2023), they must also recognize the intricate interplay between various elements within these systems. The significance of feedback mechanisms cannot be overstated, as decisions made in this regard can trigger cascading effects across different dimensions, potentially leading to the accumulation of undesirable outcomes (Morecroft, 2023; Ellen MacArthur Foundation, n.d.

(b)), a perspective underscored by the principles of systems thinking. Early-stage phases have the potential for significant changes, as approximately 80% of the CO2 footprint associated with buildings is determined during these stages (McAloone & Bey, 2009). Consequently, the integration of systems thinking into the design process becomes paramount to mitigate such adverse outcomes (Vezzoli et al., 2021), aligning with the central objectives of the thesis. Additionally, understanding casual relationships and anticipating rebound effects is essential for devising effective PSS for buildings. In this context, tools grounded in systems thinking, including nature to push for such analysis of causal relationships, serve as invaluable aids for modeling and scrutinizing the intricate interactions within a PSS (Sassanelli et al., 2018). Thus, the conclusion can be drawn that system thinking provides researchers with a leverage to discern and identify critical elements, inputs, and areas requiring attention, thereby facilitating more informed decision-making and intervention strategies.

Scholars have highlighted the application of systems thinking coupled with life cycle assessment (LCA) as an effective approach to analyzing value delivery (Metic & Pigosso, 2022). This method prioritizes collaborative solutions that integrate various stakeholders and resources (Forlizzi, 2013). Such an approach is advantageous as it allows for a focus on some aspects of the PSS and facilitates the interconnectedness of elements whose details are initially unknown within the inherent complexity of the built environment. The intricate interplay between elements of PSS poses unique challenges for the successful design and implementation of solutions (Gibb & Marsh, 2019). These challenges are particularly pronounced during the initial stages, where decision-making heavily relies on intuition (Yang & Xing, 2013). Systems thinking frameworks allow for the creation of scenarios that explore different design options and their potential impacts (Forlizzi 2013).

3.4. Legislative initiatives

On a broader scale besides national laws, the European Union (EU) is making a significant shift towards a more sustainable approach making efforts for alignment of stakeholders to create a unified approach, particularly in the construction sector. The current linear approach in construction has become a substantial consumer of resources and pollutants (European Commission, 2015; European Commission, 2020a). Hence, public sector policymakers play a crucial role in influencing market behavior as they send signals to the entire market to encourage a shift in practices (Vezzoli et al., 2021).

In 2015, the European Commission published a framework, which aimed to stimulate Europe's transition towards a circular economy model. While primarily focusing on minimizing waste, (European Commission, 2015) the plan outlined 54 actions with targets for 2030 and 2035 (Ellen Macarthur Foundation, 2022). These promoted sustainable production processes and consumption (European Commission, 2015), such as encouraging simpler disassembly and recyclability of products (Directive 2009/125/EC). However, this initial plan had limitations with its focus on waste. So, the European Green Deal framework launched in 2019 emphasized the need to further refine policies for tackling climate and environmental challenges (European Commission, 2019). This broader approach aims to achieve climate neutrality by 2050 and addresses key areas like clean environments (reduced CO_2 emissions, pollution elimination, biodiversity preservation), affordable energy, smarter transportation, and improved quality of life (Norton Rose Fulbright, 2021). The plan also acknowledges worker rights (European Commission, 2019).

As the EU prioritizes circularity, PSSs are increasingly seen as a key tool for achieving climate goals and building a sustainable future (European Commission, 2020a). Hence, in 2020 a new circularity action plan was set in place (European Commission, Directorate-General for Environment, 2020) that became a cornerstone for the European Green Deal. A revised plan reiterated the goal of circularity through setting in focus efficiency to minimize waste generation and maximize product value retention as much as possible. This was much wider as it emphasized a need for systematic change and the involvement of a wide range of stakeholders (European Commission, 2020b).

The existing and upcoming EU legislation is reshaping the built environment sector's landscape, exerting significant pressure, and pushing for circularity (Arbinolo, 2023). This is why there is a need for a bigger push from both the national and local governments to favor the creation of waste recycling systems, and sustainable models by setting clear directions, removing barriers to implementation, and creating an environment that can foster innovation and productivity in circular practices. Initiatives like circular public procurement or the standardized metrics for measuring circularity can further support these efforts. Legislation acts as an incentiviser, then to circularity approaches, including PSS (Vezzoli et al., 2021).

4. BUILDING'S ECOSYSTEM

This chapter dives into the more specifics of the modular temporary building ecosystem. This phase involves critical thinking, delving into factual data, and employing logical analysis to better understand the current situation (Forlizzi, 2013). The synthesis phase combines a review of the literature and gained insights from the interviews with the specialists to add onto the already provided background.

4.1. Current situation

Mature industries, such as built environment, often present significant challenges when introducing systemic changes. Over the years, the industry has evolved into a complex ecosystem, characterized by fragmentation along multiple dimensions. The industry exhibits vertical fragmentation, with specialized firms responsible for discrete segments of the production process (Howard et al., 1989, Fergusson & Teicholz, 1996, as cited in Hall et al , 2019). As a result of compartmentalization, there is a lack of holistic oversight, making it difficult to implement systemic changes like PSS adoption (Levitt, 2007). Furthermore, horizontal fragmentation is prevalent, with a wide range of firms competing in an extremely competitive environment (Howard et al., 1989, Fergusson & Teicholz, 1996, as cited in Hall et al , 2019). It is often the result of this intense competition that short-term gains and localized solutions are sought rather than the development of more comprehensive, systemic improvements. Oftentimes the project-based relationships between clients and suppliers are transitionary causing longitudinal fragmentation. This discontinuity disrupts the sharing of knowledge and best practices, which further impedes the creation of sector-wide solutions (Katila et al., 2018).

Hence, the widespread adoption of PSS in housing presents a challenge as a unified understanding of the approach is elusive. Research is scattered across different disciplines with limited connections making the development of comprehensive solutions difficult. Ghafoor et al. (2023) highlight this difficulty, emphasizing the need for a systemic approach. In his work he proposed a definition for PSS to unify approach for housing: "A life cycle approach that combines housing product(s) and service(s) in a system to priorities efficiency, longevity, and sufficiency in delivering the required user functionality for housing energy, material, and space use." (Ghafoor et al., 2023, 8) His approach can be transferred to modular temporary buildings as the principles are similar; one form of housing can be temporary modular buildings.

While PSS has the potential to drive positive change through capabilities like longevity, sufficiency, and efficiency, not all of these capabilities are always implemented equally as also discussed above (Ghafoor et al 2023). The core strength of the PSS approach in buildings is its ability to focus on resource reduction by keeping the product in use multiple times with a long-term focus on maximizing functionality (Bertino et al., 2019). The principle can be seen in the illustration in Figure 4, which shows how the material and product flow operates within the system. However, addressing these outcomes, as it became apparent that negative outcomes may overshadow the intended benefits (Metic & Pigosso 2022), presenting further challenges.

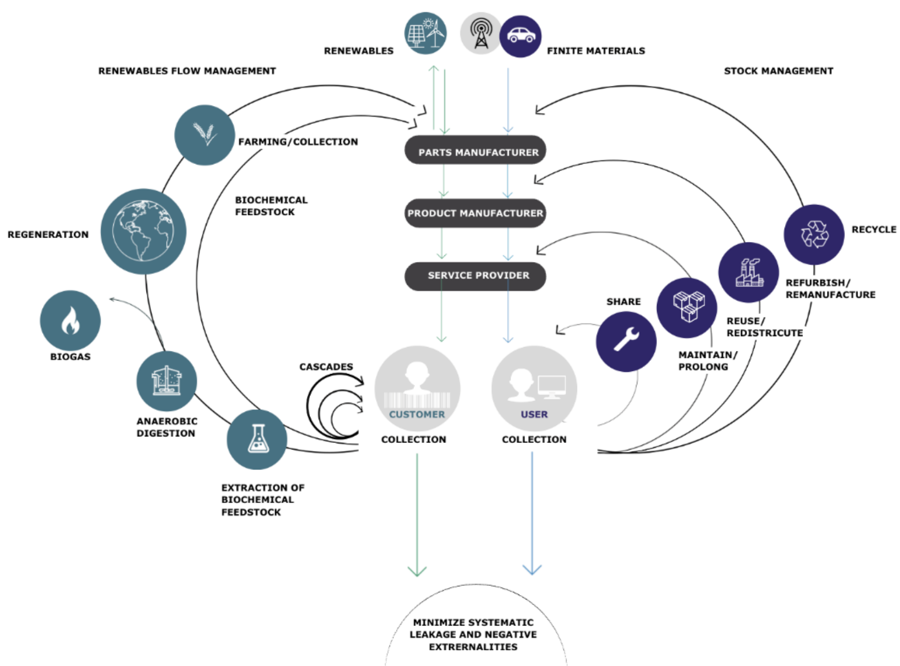

Figure 4: Butterfly diagram. Source: Ellen Macarthur Foundation, n.d. (b)

The context of buildings remains unique due to the specific business models involved. Opportunities for closing liability loops and implementing circularity within the construction and built environment are limited, partly due to a lack of extensive knowledge in the field (Ghafoor, 2023). Additional complexity arises with changing legislation, where companies are reluctant to make alterations before the changes are made within the regulations. This creates a paradox: the longer the changes are delayed, the harder they become to implement as previous choices become interconnected to the other elements and decisions. Therefore, professionals agree that the best option should be considered from the beginning to maximize positive outcomes and minimize negatives (Interviewee Y1, Y6; Alfarisi et al., 2022).

In such a PSS circularity, cascading plays a crucial role. It involves diverting leftover materials, also known as the sidestream, from one production process and using them as the starting point, or feedstock, for the next (Borregaard, (n.d.); Ellen Macarthur foundation, n.d. (b)). This strategy maximizes the value of raw materials. Instead of creating waste after a single use, the materials are maintained, reused/ redistributed, refurbished/ remanufactured and/or recycled (Ellen Macarthur foundation, n.d. (b)). This approach can be particularly effective in building models. Designing for adaptability encourages flexible layouts or modular components enabling reconfigurations based on the need (Oorschot & Asselbergs, 2021). Materials that are made for disassembly, along with efficient take-back, help circulating resources to be reintroduce to the buildings' system. This approach minimizes waste and maximizes the value of the resources (Galle et al., 2019). Additionally, it provides a solution to a specific context that also enables sharing space. This can lead to reduced space needs and encourage better space planning, even in higher-density urban forms (Cohen, 2021). In addition, training users on proper operation, implementing preventative maintenance schedules, and utilizing monitoring and upgrade programs can support effectiveness (Bertino et al., 2019).

4.2. Applying PSS in buildings

Within the industry, significant responsibility rests upon the shoulders of business owners, particularly due to the relative lack of established knowledge in this domain. As previously pointed out then the entrepreneurs embarking on such sustainability approach theory often rely on intuition or prior experience, confronted with many choices and considerations (Yang & Xing, 2013). Recent research by Pieroni et al. (2020) has delineated that only making circular business model related choices 20 distinct archetypes can be distinguished, comprising 63 sub-types, underscoring the intricate decision-making processes inherent in this field. Making the best decisions lays the foundation for well-functioning systems. Good governance process provides also an environment that is considered safe, healthy, with increased potential for well-being (Interviewee Y5), as well as diverse and inclusive (Interviewee Y6). For example, the need to increase lighting can lead to unintentional benefits from an environmental perspective due to its energy efficiency, even though sustainability was not the initial plan in such decision. This illustrates that there are a lot of decisions; sometimes these arise from needs, available capabilities or best-known practice (Interviewee Y5).

With the options available to companies, compounded by the integration of PSS elements, business owners encounter though challenges, especially in the early stages where resources, including financial means, may be constrained. Yet, the experimental phase importance remains high (Bocken et al., 2016), providing opportunities for testing and idea generation within a controlled environment characterized by fewer variables influencing outcomes. This controlled setting facilitates learning from errors and iterative enhancements, guiding the formulation of novel business models while accruing empirical evidence (Zink and Geyer, 2017). As discussed by Mont (2004), complete foresight is unattainable; however, informed decisions prompt increasingly refined estimations when done systematically (Yang & Xing, 2013).

This process is indispensable because unintended outcomes, as expounded earlier, possess the potential to diminish the benefits of implementing such models. It is imperative for companies and their founders to ensure the robustness and future-proof nature of their envisioned concepts, aware of possible differences between expected and real results. Effecting modifications later in the project lifecycle becomes progressively harder and cost intensive (Yang & Xing, 2013). While consultants are often engaged for this purpose as found from interviews, financial constraints may preclude their involvement in the early design phases, necessitating a greater reliance on individual assumptions, intuition, and experiential insights. Considering also the fragmentation as investigated previously the mutual learning oftentimes is not part of a common practice (Katila et al., 2018).

4.3. PSS Value Delivery

The successful implementation of PSS in the industry requires careful planning, particularly given the industry's maturity and complexity (Ghafoor et. Al 2023). Thus, this section explores how PSS value is delivered through various stakeholders.

Galle et al., (2019) proposed three distinct models for leveraging the existing ecosystem to deliver access-based ownership models effectively. The first model features a central owner and manager who takes full responsibility for the product through contracts with users, relieving them of ownership burdens of maintenance. The second model introduces shared ownership between the company and various suppliers. Long-term contracts establish shared responsibility for performance and product quality across the network, although this increases complexity. Finally, the third model proposes a fully supplier-based network where users contract directly with individual service providers. Latter potentially reduces costs for users, but requires more stakeholders, including industry organizations and government agencies, to ensure sustainable operation.

Diverse stakeholders are engaged by these various models of PSS, which facilitates knowledge sharing and mutual learning within the network (Kurdve & de Goey, 2017). Köhler (2022) further emphasizes the importance of close communication for successful PSS implementation. Without it, challenges arise in collecting and analyzing relevant data. Yet, a synergy among all the participants is required (Interviewee Y5) necessitating balance. While it offers advantages by bringing together specialized skills and expertise to deliver all aspects of a function, it can also lead to increased complexity (Mont, 2004). Often, due to numerous suppliers or stakeholders, not everything is fully known, and relationships tend to rely heavily on trust not data (Interviewee Y5, Y6). This complexity can manifest as communication challenges and higher transaction costs. Therefore, effective collaboration strategies are crucial for ensuring successful function delivery with a larger team. Companies must carefully navigate this trade-off to leverage the benefits of diverse expertise without sacrificing efficiency or competitive advantage (Mont, 2004); Köhler 2022).

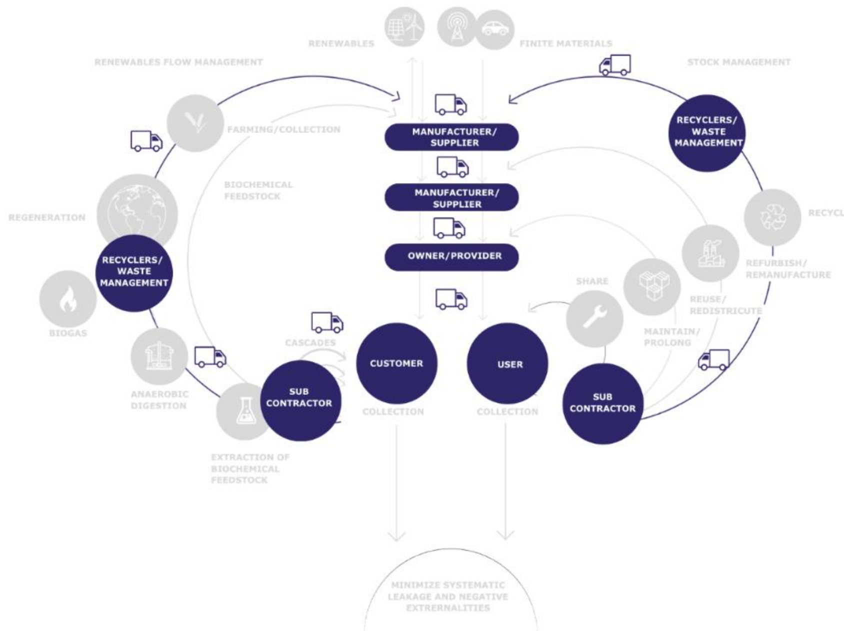

Figure 5: Stakeholder map. Source: Author, based on (Ellen Macarthur foundation, n.d. (b))

The interconnected nature of PSS goes beyond just needing collaboration – it fosters a whole web of relationships (Fatourou-Sipsi & Symeonidou, 2021). Architects now need to design with end-of-life in mind, fostering collaboration with deconstruction specialists (Köhler et al., 2022) and waste recycling system representatives (Vezzoli, 2021) to ensure buildings can be easily broken down for secondary building material (Köhler et al., 2022) or maintained and repaired by outsourced partners. Driven by the focus on well-prefabricated products, providers often have dedicated in-house design teams heavily involved in both design and production to make sure that the network of designers, consultants, manufacturers, and suppliers seamlessly integrates with the overall product lifecycle (Oorschot & Asselbergs, 2021). However as PSS is not a widely applied approach yet, there are challenges in alignment. Direct customers still at times tend to turn to the architects that generate an idea that is not feasible within the domain of S.PPS. This results in extra time and effort to be needed to redo the entire process from the beginning (Interviewee Y1). For instance, not all roof types can accommodate solar panels, highlighting the importance of selecting compatible elements and modules during the design phase (Interviewee Y6).

Close collaboration with manufacturers, or in some cases, vertically integrated companies that handle both manufacturing and construction, is crucial for maximizing the inherent value of materials, components, and the final product. Involving suppliers early in the design phase, facilitated by material passports, has been shown to significantly increase circularity. This is because all building details are documented, ensuring informed decisions about material selection and future reuse potential (Huovila et al., 2019). Considering that each component has its own lifecycle, timely exchanges are essential for achieving optimal results (Fatourou-Sipsi & Symeonidou, 2021). Leveraging digital platforms can enhance this process by providing a better overview of supply and demand, thus ensuring effective reuse of materials, and minimizing the need for virgin resources (Çetin et al., 2022).

According to estimates from the Delta Institute, only a small percentage, ranging from 5% to 15% of materials resulting from the demolition of residential buildings are unfit for recycling. Notably, about 25% of these materials, including windows and doors, can be directly repurposed, while a significant 70% of raw materials like concrete can be processed for reuse. This underscores the financial viability of deconstruction and highlights its potential to create additional job opportunities across various sectors. These opportunities extend to construction workers, warehouse personnel, sales representatives, renovators, and individuals involved in construction skills training, particularly in disassembly and renovation techniques. Experts even suggest that for each person engaged in building deconstruction, an average of seven additional jobs are created in material processing activities (Delta Institute, 2018). As stated, the industry has a strong foundation for job creation, this was further recognized by interviewee Y4. However, as there is frequent use of heavy machinery, there is an increased risk of accidents and injuries, which must also be considered (Interviewee Y5).

As companies increasingly prioritize responsibility and ownership, they are actively seeking ways to extend product lifecycles and reduce costs. Material selection plays a key role here, with strategies like utilizing durable materials and sourcing from secondary, upcycled, healthy, local, and/or bio-based sources being increasingly adopted (van Stijn & Gruis, 2019). Standardization of offerings (Oorschot & Asselbergs, 2021) or lightweight (Mrkonjic, 2007) designs can further support these efforts. Lightweight materials (mostly used for wood) not only enhance safety but also bring biophilic benefits (Interviewee Y7). The biophilic effect, which emphasizes connections with nature, has been shown through numerous studies to have positive impacts. Contact with nature can reduce stress, increase self-esteem, lessen anxiety, etc (Salingaros, 2019) Additionally, implementing disassembly practices by minimizing the number of parts and ensuring they are demountable enables easier replacement of components, positively impacting longevity. This in turn helps to mitigate the incentive for price hikes, lessens the amount of GHG emissions, and demolition (C&D) and packaging waste (van Stijn & Gruis, 2019). However, a considerable amount of energy- and carbon-intensive steel is still being used, prompting the search for alternatives (Interviewee Y5).

The efficiency of such demountable modules has the potential to lessen the assembly time to counted days (Interviewee Y7). Through this, the building can achieve a level of airtightness that would be unattainable using traditional construction practices (Interviewee Y2). Moreover, modularity enhances quality control and transparency: some companies even document each layer through photographs that later must be representable (Interviewee Y1). This comes handy considering the temporary characteristic, these modules serve many purposes throughout their lifespan, supporting hospitals (Interviewee Y2), schools (Interviewee Y2, Y8), housing associations (Interviewee Y4), etc. Each location where the modules are transported have its unique impact on the modules, altering product indicators and complicating universal tracking and evaluation (Interviewee Y3). Efforts are made to lead to better operational energy and water efficiency, optimizing lifecycle management. However, the efficiency and resource consumption of buildings are significantly influenced also besides the location by tenants and businesses occupying the space. Therefore, their role is crucial as well. Bridging the gap between provider expectations and user behavior is a key challenge, highlighting the importance of educating users to enhance sustainability outcomes. (Oorschot & Asselbergs, 2021), interviews also directed to this same challenge.

In fact, business case examinations and interviews revealed a potential misalignment between occupants and implemented PSS models. While contracts typically involve businesses (B2B), actual occupants are left out and may have different priorities, hindering the intended impacts of PSS in the industry (interviewee Y2). This observation is consistent with another interviewee's remarks on how people tend to prioritize daily tasks over engaging with sustainability features. For instance, users often neglect to read instructions for machinery and appliances, such as heating systems (Interviewee Y3) or switch the lights off (Interviewee Y6; Ackermann & Tunn, 2024). Most interviewees noted that once buildings are handed over, occupants use them freely, limiting providers' control, especially regarding sustainability (Interviewee Y2, Y6). Despite residents paying electricity bills, providers bear responsibility for associated CO_2 emissions due to ownership. Hence, it is essential to consider their potential actions during the early design phase (Interviewee Y2).

Additionally, companies examined are currently increasingly incorporating digital solutions that offer real-time monitoring capabilities (Interviewee Y2, Y3, Y4, Y5, Y6, Y7, Y8). This allows for optimization of service delivery (e.g., ventilation systems automatically adjusting based on sensor data) (Interviewee Y8). While these advancements might suggest a reduction in on-site personnel, the need for skilled professionals remains crucial. The rise of demountable solutions, for example, necessitates expertise in the assembly and disassembly of building modules and addressing interior and exterior elements as mentioned above by Delta institute. Hence, subcontractors continue to play a vital role in construction, ensuring adherence to standards as they transport, assemble, or construct offerings on-site. Their work directly impacts community well-being and user satisfaction as often they are closest to the users and clients physically. Beyond construction practices, their activities also influence various aspects of the final product, including environmental impact, sound pollution, and indoor quality (light, air, etc.) (Interviewee Y2; Vezzoli, 2021).

While the goal is to establish optimal service or a closed-loop system, not all companies from the interviews have fully embraced this journey yet. Although many are taking steps in that direction, the complete adoption of circular practices remains a work in progress. Some companies face challenges like finding suitable partners. For instance, during interviews, it was revealed that one company must import materials from Sweden to meet sustainability production requirements and then export them back, complicating the retrieval of old materials. To some extent, they can resort to recycling through governmental waste systems or returning products to the original manufacturer, despite the noticeable distance involved. In other cases, more innovative solutions are explored, such as donating products for local home-based projects. However, despite these efforts, some materials still find their way into landfills (Interviewee Y1). In some cases, there is insufficient incentive to focus on finding alternatives or recycling. Companies can earn money by handing off materials to recycling, which helps close the loop but does not encourage efforts to avoid waste in the first place (Interviewee Y5). Sometimes it is also just not feasible to use up everything, such materials are then either remanufactured or incinerated (Interviewee Y6, Y4).

Looking more broadly, as Mont (2004) noted, companies are significantly affected by society and wider context. For companies to stay competitive they most need to follow the trends. For instance, seriously consider biomimicry to be socially preferred but also to amplify the positive outcomes. More focus is also being set of ethical management and ESG, which pushes companies to incorporate new measurement ways into their practice. (Interviewee Y5). Yet, such changes are at times difficult, as the legislation is lagging or regions are affected by political situations, wars (Interviewee Y1), COVID-19 (Interviewee Y8), or in the Norwegian context, people through communication and idea generation within the community keep setting standards for better solutions (Interviewee Y1). These factors in turn affect the feasibility of value delivery. Just an example, a company had taken a decision on how to lessen the GHG emissions, only to find out in a year that the direction is no longer accepted in the eyes of public (Interviewee Y6). These factors illustrate the dynamic and often unpredictable environment that companies must navigate. Successfully managing these challenges requires flexibility and adaptability, underscoring the importance of strategic planning and responsive operations in the implementation of PSS.

5. RESULTS AND DISCUSSION

The focus of this study was to address the central question: "What are the key elements that companies must consider when designing product-service systems?" This endeavor involved a thorough examination of the operational context of PSS, which subsequently led to an exploration of various sustainability dimensions and components, including economic, environmental, social, governmental, technical, and behavioral aspects. With a specific focus on the built environment, particularly in modular temporary buildings, it became evident that despite often being focused as network actors, end users have significant influence over the outcomes of PSS, yet they are mostly not included, among other potential outcomes.

Employing systems thinking principles, this study acknowledged the interconnected nature of various elements and perspectives. Initially, it examined a broader perspective of relevant aspects pertaining to PSS, which was subsequently refined through a contextual lens. This approach facilitated an understanding of the outcomes, categorized into legislation, governance, maintenance, reuse, refurbishment/remanufacture, adaptability, low cost, and ownership. For clarity and to avoid repetition these findings are summarized in the table in Appendix 3.

The above research and findings highlight the essential task of achieving balance among the various elements and dimensions within the built environment, which presents complexities beyond the typical environmental, economic, and social dimensions inherent in PSS, to effectively optimize their intended outcomes. Despite careful planning, PSS initiatives may confront obstacles during execution, emphasizing the necessity of a comprehensive understanding of potential problem areas. Furthermore, the analysis underscores the critical importance of obtaining a thorough grasp of the current state and opportunities within the built environment industry to design PSS successfully. In the initial design phases, companies often encounter challenges due to limited comprehensive information, relying heavily on intuition or previous experience (Yang & Xing, 2013). To overcome this challenge, it is recommended that businesses adopt systematic and robust methodologies to augment their understanding, particularly in environments where knowledge sharing is restricted (Forlizzi 2013; Yang & Xing, 2013; Geissdoerfer et al., 2017; Iacovidou et al., 2021). Additionally, given the legal pressures and holistic decision-making challenges faced by business owners in isolation, effective communication and collaboration among diverse stakeholders emerge as indispensable factors for achieving success (Köhler, 2022).

5.1. Problem statement

The research findings not only establish an insight into understanding the outcomes PSS for buildings are facing but also highlight the need for decision-making support during the initial stages of PSS design, particularly when faced with limited information and reliance on intuition. Companies embarking on PSS ventures confront significant obstacles, including fragmented industry landscapes (Howard et al., 1989, Fergusson & Teicholz, 1996, as cited in Hall et al , 2019; Katila et al., 2018), resource constraints (Yang & Xing, 2013), and the complexity of integrating PSS components (Mont, 2004). Moreover, the lack of a unified understanding and holistic approach further complicates the design process in the industry as found (Metic & Pigosso, 2022).

Therefore, the problem statement guiding PSS design in the early stages of company decision-making is formulated as follows: How to support companies with the adoption of product-service systems in the early design stages? This problem statement serves as the foundation for the design concept, which seeks to help companies navigate the complexities of PSS design, generate ideas, and make more informed decisions that consider sustainability. Addressing this problem, the statement has the potential to support companies to overcome barriers to PSS adoption and drive positive change within the built environment industry. The concept development objectives can be found in the next chapter.

6. DESIGN PROCESS

This chapter endeavors to delve into the mechanisms for supporting business owners in embracing PSS business models. At its core, the objective is to empower early design phase companies to cultivate their innovative solutions, particularly in their sustainability journey. This goal is underpinned by the application of a systems thinking model, as proposed by Bui and Galanou. Their framework focuses on the imperative of aligning organizational objectives with the broader systemic context. For this work, it includes data analysis, concept planning, testing, and evaluation. By fostering a deep understanding of the environment in which buildings operate, businesses can delineate clear objectives and make informed decisions also about the application of PSS (Bui & Galanou, 2022). Hence, this chapter is looking for answers to the question, which was presented in the previous chapter.

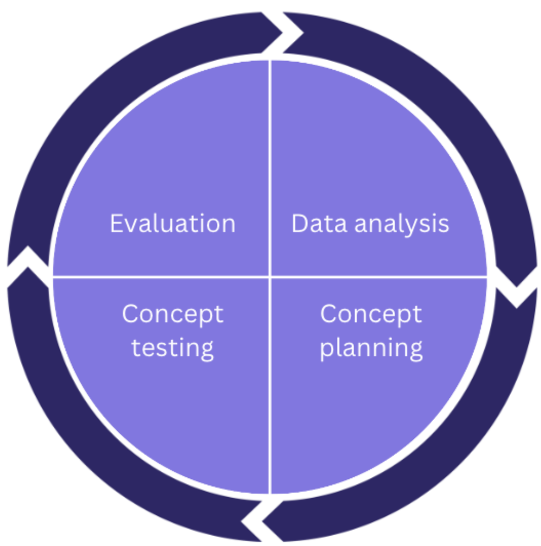

Figure 6: Process of translation of systems thinking to organizational goals. Source: Adopted from Bui & Galanou, 2022

6.1. Data analysis and concept planning

Data analysis lays the foundation for the design process by providing a framework that becomes the cornerstone of the concept. These processes help in understanding the design requirements and identifying the necessary elements for effective implementation for the initial prototype (Bui & Galanou, 2022).

6.1.1. Understanding what needs to be designed

Stemming from the research conclusion, several approaches were explored in the initial phase of analysis when brainstorming. This was crucial as it enabled further exploration of what could be potential opportunities for the concept development (Dam & Siang, 2019). Hence, initially, one approach appeared promising for the screening phase, setting into focus longevity, sufficiency, and efficiency, which are key capabilities in the built environment within a PSS context (Ghafoor et al., 2023) and companies are working towards achieving these. However, upon closer examination, it became evident that these criteria did not align well with the intended goal, as these capabilities are typically factoring professionals compare their solutions to during evaluations and remain superficial.

Subsequently, the focus shifted towards emphasizing the sustainability dimension, as outlined by various authors, which advocates for a balanced approach across all dimensions. A well-planned approach enhances the likelihood of achieving desired results. Additionally, this approach aids in mitigating RE or any other undesirable outcomes as it provides more holistic earlier detection (Geissdoerfer et al., 2017). This purposeful approach is necessary because undesired outcomes have the potential to undo the benefits. (Metic & Pigosso, 2022). For such approach as highlighted in the problem statement (see section 1.2) by Pomponi & Moncaster (2017), the built environment encompasses various dimensions beyond sustainability. They emphasized the importance of considering economic, environmental, behavioral, societal, technological, and governmental factors. Therefore, for initial testing, these dimensions were integrated into the tool (see Figure 7).

Additionally, adopting a systematic approach, as emphasized by Yang & Xing (2013), and consistently referenced throughout this work, is essential for a thorough and holistic exploration. This approach is particularly beneficial during the early design phase, where it proves to be the most effective strategy. So, in this work Mont's elements—product, service, infrastructure, and network of actors (see more details in section 3.1.2)—were integrated to provide a comprehensive framework to establish such grounds. Yet, a downside was noticed, this framework excludes the users, who are relevant within buildings context. This was also highlighted by the interviewees, who are only now also starting to integrate more into their design processes and finding ways to insert themselves to the usage phase. Therefore, contextual network/users are proposed to be added to gain more holistic overview. The contextual network consists of users who are not included in the contracts but continue to use the building in their daily activities, such as work, school, hospital visits, etc.

Although the contextual network was highlighted in the separately as having a significant impact to the offering, it's essential to emphasize equality without favoring one over the others. The goal is to achieve the best possible outcome across all areas by minimizing negative outcomes and maximizing positives. This can only be accomplished by making the best possible decisions and this can be done by maintaining an emphasis on equality among all elements and dimensions.

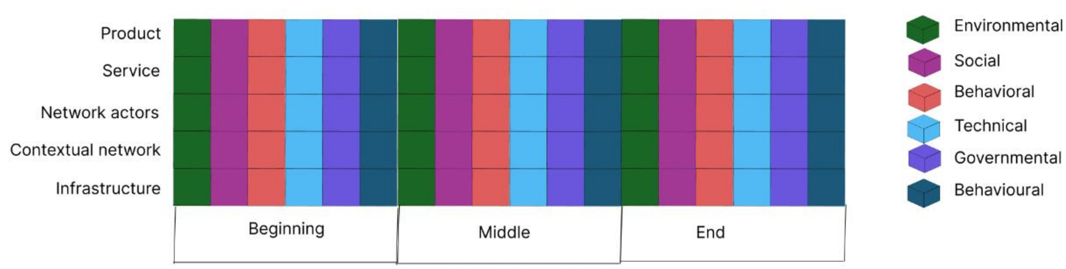

Figure 7: First prototype. Source: Author

Considering the dynamic nature of the environment and the uncertainty surrounding product lifespans highlighted in interviews, it's crucial to address the temporal aspect of the overall offering while recognizing the relevance of various elements. This approach allows for the recognition of changes in these elements and dimensions over time. Therefore, a holistic approach encompassing the beginning, middle, and end stages was initially adopted. Researchers like Metic and Pigosso (2022) advocate for the potential of Life Cycle Assessment (LCA) in supporting this objective. However, further investigation reveals that while LCA offers valuable insights, its static nature limits its perspective to analyzing only the environmental impact over a single service life (Eberhardt et al., 2020; van Stijn et al., 2021). This approach lacks the necessary granularity to fully understand the lifecycle impact. To achieve the intended balance, the principles of cascading discussed in the chapter 4, which illustrate material flow and have shown potential from a temporal perspective according to Metic & Pigosso (2022), are adopted. These cascading principles are incorporated into the instructions and idea generation part.

As mentioned earlier, systematic adverse effects, particularly negative ones whether behavioral or otherwise have been identified in relation to inactivity (Alfarisi et al., 2023). Therefore, the primary objective of criteria is to encourage companies to explore alternatives and generate ideas for achieving balance through potential alternatives in the final business model.

6.1.2. Design requirements

Stemming from analysis design requirements were set as to incorporate features that excel not only within singular sustainability dimensions but across multiple dimensions as well having the potential to maximize positive effects (Alfarisi et al., 2022). Hence, the following identified tool requirements are primarily based on interviews and supported by research analysis:

- **Sustainability analysis:** The tool should empower companies to thoroughly examine all aspects of sustainability related to their offering.
- **PSS-focused**: The tool should be capable of analyzing every element – product, service, network actors, infrastructure - within a company's PSS model, including determined contextual users (see 6.1.1).
- **Time analysis:** The tool should allow for the understanding of sustainability impacts over time, considering how elements may evolve.
- **Systematic outcome exploration:** Users should be able to systematically explore both positive and negative outcomes associated with their PSS offerings. Including both types of outcomes enhances understanding and helps identify causal connections between different aspects.
- **Mitigation Strategies:** The tool should additionally go beyond merely identifying negative impacts by offering users the ability to formulate mitigation activities. This pushes beyond inactivity by incorporating the proactive approach already in the

early design phase. Even if complete avoidance is not feasible, efforts to balance or mitigate these effects could still lead to significant improvements in sustainability performance.

6.2. Concept testing and evaluation

Iterative prototyping and testing are vital components of the design process, serving to validate the most promising ideas generated during the ideation phase. By gathering feedback from professionals and/or users on the design concept, this iterative approach aligns with the needs and enhances the potential for real-world application in the future. (Interaction Design Foundation, 2019)

As outlined in the methodology, testing was done to evaluate the components' applicability and usefulness in four separate co-creation workshops (see Table **Error! Reference source not found.**). Two sessions involved discussions with a Rental Operations, Sustainability, and Engineering Manager from a company with over 30 years of operational experience, and another two sessions included an experienced co-founder with significant industry expertise but whose company is in the early design phase. The summary of those can be found in Appendix 4.

6.2.1. Testing 1

The evaluation conducted regarding the initial segment of the tool (see Figure 7) demonstrated promise, alongside important observations. The form's lengthy appearance evoked intimidation, necessitating optimization to alleviate reluctance. Additionally, while the addressed dimensions remained relevant, a perceptible overlap was identified, potentially compromising the tool's efficacy. The economic dimension, closely linked with profitability, was found to be best integrated with regulatory, technological and governance dimensions to ensure the inclusion of pertinent dimensions in compliance with industry trends and regulations. Similarly, the social dimension can be closely associated with behavioral aspects, leading to the decision to consolidate these aspects in the refined prototype.

6.2.2. Improvement 1

Following the identification of necessary improvements, adjustments were implemented accordingly. In line with recommendations, the governmental and social dimensions were expanded and accordingly, other mentioned dimensions were integrated (see Figure 8). Recognizing the need for guidance, inspiration was drawn from trending and essential reporting practices (see Appendix 5).

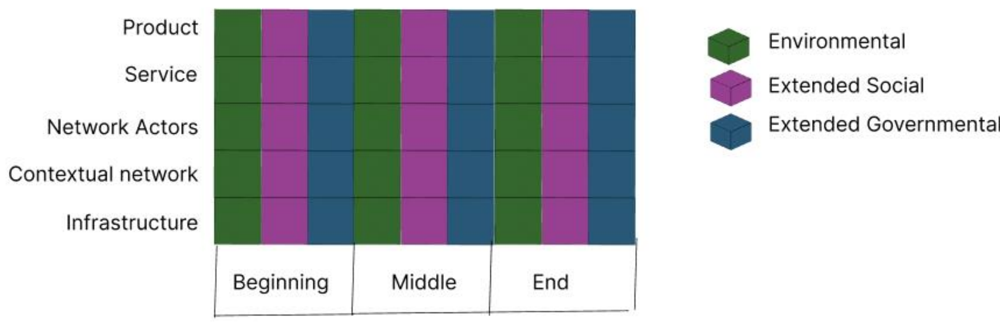

Figure 8: Second prototype. Source: Author

The inspiration drawn from industry reporting practices, particularly ESG reporting, stems from importance in guiding businesses to stimulate idea generation while ensuring alignment with industry standards (Deloitte, n.d.; PwC, n.d.) and trends. ESG reporting has emerged as a prominent framework for capturing non-financial considerations, showcasing a company's commitment to environmental sustainability, social responsibility, and ethical governance practices. In the context of buildings, where complexity is amplified due to its maturity, these dimensions emerge as critical factors that directly impact sustainability efforts and investor appeal. By integrating ESG principles into sustainability considerations within reporting practices, businesses can strategically position themselves for sustainable growth while meeting stakeholder and investor expectations. The incorporation of governmental dimensions and the adoption of sustainability principles, inspired by PwC's (n.d) methodology (see Appendix 5), reflect a proactive approach towards enhancing business sustainability and navigating the complexities of the industry landscape effectively. This will later be used within the tool itself with further instructions that area meant to spark idea creation. It's important to mention as a reminder that RE often stems from diverse areas including efficiency, economics, environment, circularity, and social factors, and is influenced by shifts in time, money, space, or technology (Metric

& Pigosso, 2022). Hence, these aspects warrant increased attention and deliberation, which is why these are also incorporated in the guidelines.

6.2.3. Testing 2

With the sustainability dimensions now established with beneficial guidelines that are approved by industry professionals, the focus shifted to determining how best to present them in a format that would be readily understandable and applicable within the workflows of companies, aiding in their creation. The primary concerns identified during these evaluations centered around a perceived sense of stagnation, which hindered participants' cognitive processes. Participant noted that the current format, depicted as static squares, failed to evoke the concept of circularity or prompt engagement with it. Participants suggested that, particularly when considering circularity principles, the tool should facilitate visual representations that better capture the dynamic nature of the concept. Furthermore, they underscored the importance, especially for companies in the early design phase, of describing the lifecycle—from inception, through the contractual period, to the end of component lifespans.

6.2.4. Improvement 2

Consequently, a more dynamic prototype was developed, as illustrated in Figure 9.

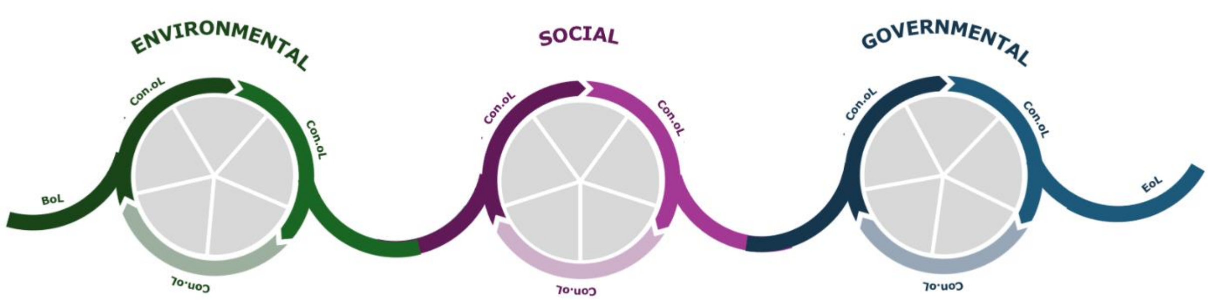

Figure 99: Third prototype. Source: Author

To finalize the second part of the approach, efforts were focused on enhancing its dynamism. This involved establishing a holistic approach to comprehensively examine outcomes and push for proactive strategy exploration for mitigating these adverse impacts. The implementation of the "5 Whys" design thinking approach enabled the efficient identification of causal connections while remaining straightforward enough to match the level of knowledge and time commitment required during the design phase of the business model. Users are pushed to ask “why” five times ensuring that underlying issues will be addressed beyond the superficial level, which is crucial in navigating complex systems like buildings have. By adopting this approach, providers of PSS are empowered to evaluate their options and strive to offset any adverse effects if possible. As mentioned before, some negative outcomes may prove challenging to avoid entirely, which is why making right decisions already early design phase is a must (Interaction Design Foundation, 2016b). This is illustrated in Figure 10 with a service community dimension.

SOCIAL		BENEFITS	UNINTENDED CONSEQUENCES	5 WHY's	RISK	ALTERNATIVES/ MITIGATION
COMMUNITY	Infrastructure investment					
	Community empowerment					
	Engagement and exclusion					
	Health and safety (Chen 2021)					

Figure 10: Part of the tools’ extended prototype. Source: Author

However, for actual change to occur there is a need to push companies towards seeking alternatives, as merely recognizing the need would deepen the inactivity. Instead, optimal impact reduction shall occur (Alfarisi et al., 2023). To address this challenge, a risk assessment tool (see Appendix 6) was adopted, leveraging research-based user experience expertise that is simple enough yet again in the times to optimize time used. Such an approach is also in correlation with what is known at these times and serves as an invaluable tool, offering early detection of most issues and what can be left in the later stages (Fessenden, 2023). Subsequently, a refined prototype was assembled based on the outlined screening criteria to assess its suitability and effectiveness in achieving the identified objectives.

Another crucial aspect addressed was delineating the lifecycle of the offering. Recognizing the importance of achieving a comprehensive understanding of what idea they have at the starting point, especially in the early stages of design where uncertainties may often arise. Through performance indicators, companies are prompted to gain a clear understanding of the offerings and the objectives driving them. This ensures alignment with sustainability objectives and business strategy. Nappi et al. (2024) proposed a framework that aligns with industry specialists' push to ask questions such as "where?" and "how?", aligning with the industry specialists' recommendations from the workshops. "Where are we now?" assesses the current state of performance measurement processes, leveraging existing resources a company may already have. "Where do we want to go?" pushes companies to identify strategic objectives and corresponding indicators. "How do we get there?" evaluates the transition as a process making companies consider the lifecycle of the offering from inception to the end of component lifespans. These questions are crucial as it distinguishes companies in the market and defines their transition into PSS when focusing on outcomes (Leioni & Pogessi 2017). By prioritizing such a value proposition, the tool aims to push for meaningful connections between the business owners and sustainability.

Figure 11: Performance indicators prototype. Source: Author

6.2.5. Testing 3

It was proposed that the language be corrected to industry-specific terms or completely revamped. Additionally, it was observed that if risk assessment were added, the terminology should also reflect this incorporation. Instead of "mitigation," "risk assessment" was proposed. Otherwise, the continued use of non-sector-specific vocabulary began to impede the tool's intuitiveness. Another option would be to open up each column and use other terms. Furthermore, recommendations were made to enhance the tool's level of detail, enabling it to guide the discovery and idea generation more effectively. For simplicity's sake, the professional recommended utilizing digital solutions or databases.

Efforts were made to further simplify the solution, aiming to avoid overwhelming the user. The PwC methodology, augmented with research insights for aiding idea generation, was proposed to serve as a foundation where the digital solution itself generates or suggests ideas or the user can gain insights from. Professionals recommended maintaining a more generic approach at this level, as not all aspects may be relevant to every company. This optimization not only simplifies the tool but also improves readability, reducing unnecessary complexity and getting stuck.

6.2.6. Improvement 3

Following feedback analysis, a decision was made to shift focus away from the term "risk" and instead prioritize open-ended idea generation. This adjustment aims to foster a more expansive approach to ideation, encouraging creativity and innovation without the constraints associated with the term "risk." Additionally, recognizing the need for a more comprehensive table structure, the content was expanded to include additional columns. Instead of solely focusing on risk mitigation, the table now encompasses priorities, alternatives/mitigations, and proposed changes. This expanded version allows for a more thorough exploration of potential strategies and solutions/balancing, ensuring a holistic approach to addressing identified outcomes (see Figure 12).

ENVIRONMENT	SUBCATEGORIES	SUBCATEGORIES ELEMENTS	BENEFITS	UNINTENDED OUTCOMES	5 WHY's	PRIORITY	ALTERNATIVES/ MITIGATION	PROPOSED CHANGES
SERVICE	SERVICES	Service 1 Service 2 ...						
	MANAGEMENT	Multi-user Single-user ...						

Figure 12: Part of the second iteration of tools' extended prototype. Source: Author

To maintain clarity and organization within the tool, simplification was prioritized. This involved careful consideration of how the expanded table structure would integrate with existing elements, ensuring overall coherence and functionality. The iterative refinement process aimed to strike a balance between comprehensiveness and usability, thereby enhancing effectiveness in guiding decision-making and problem-solving processes. The following iterations were made (see figure 13):

- The product category was divided into manufacturing processes and assembly.
- Service offerings were subdivided into different services and their organizational structures.
- Network actors were categorized as internal and external.
- Contextual users were differentiated as permanent and temporary.
- Infrastructure components were separated into logistics and waste management systems.

A key emphasis throughout these iterations was the importance of maintaining a generic approach that remains relevant to various business models with in even the temporary modular building models, especially during the early design phases where not all variables may be known. Recognizing that every company is unique and operates with different values, the tool was designed to provide relevant guidelines that could be customized to suit individual business models. This approach ensures that each company receives support that can be tailored through guidance to support their specific needs and objectives.

Figure 13: Helix of the extended prototype, focusing on elements. Source: Author

6.2.7. Testing 4

The final testing served to validate the proposal, aligning with the initial workshop's objective of ensuring the tool meets current industry trends and directions. It now potentially possesses the capability to guide companies through the early design process based on the professionals' own practical experiences and literature. Minor iterations were requested, such as reorganizing elements to enhance coherence within the framework and facilitating idea generation for business owners in a logical manner. Such iterations are showcased already in the refined design proposal (see Chapter 7) with the improved digital development that assists to manage extensive data, which was also supported by the experts.

7. PROPOSAL

The following chapter introduces a refined design concept and showcases its practical functionality through a business case study of a secondary housing sector company. While this company shares some characteristics for which the concept was originally developed, its partial alignment presents an opportunity to test the tool with companies that may not perfectly fit its intended purpose. This also showcases that the tool will not only work with one specific building type but could also potentially be broadened.

7.1. Helix Scope

Helix Scope is a digital platform tailored for professionals, especially those embarking on new business models, aiming to empower them with guidance and ability to systematically analyze their new innovative business model (see Figure 14). It incorporates elements relevant to S.PSS. Here all the elements have the same weight – sustainability can only be achieved if every element is treated the same way. For each element the best possible available decisions must be made. This comprehensive approach ensures that professionals consider the entire lifecycle of an offering, emphasizing its impact across various sustainability dimensions. Helix Scope offers a panoramic view of potential sustainability outcomes, equipping users with the insights needed to make informed choices already at the offering's inception.

Helix Scope's features offer valuable tools for professionals powered by an AI assistant, the platform performs analysis of what has already been written and compares it to its knowledge and makes suggestions about what else should be considered. This eliminates that in the early design phase decisions are being made only based on business owners own previous experience and intuition. Moreover, Helix Scope can also facilitate in this way a collaborative approach by enabling sharing of the information and co-creation more effectively between multiple stakeholders as the results are automatically saved in their company accounts that can be signed into by others with a password.

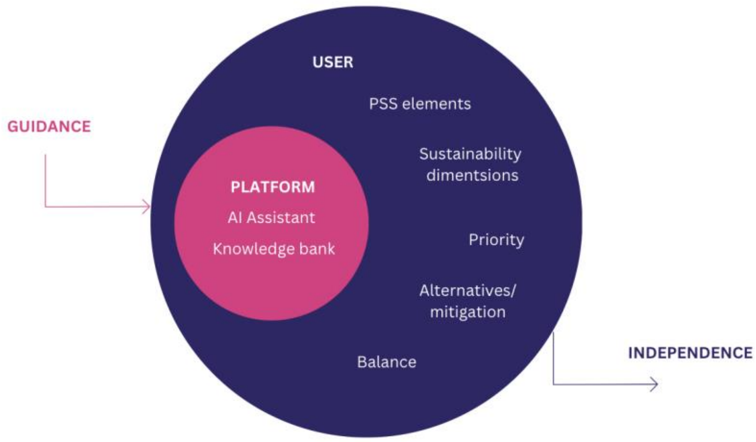

Figure 14: Service offering. Source: Author

7.2. Overview of Helix Scope

The proposed design concept aims to foster conscious decision-making by generating ideas and promoting sustainable or optimal options. To achieve this goal, a digital platform is envisioned, designed to highlight various PSS-specific elements and ensure nothing crucial goes unnoticed. The system's mapping, detailed in Appendix 7, illustrates the platform's layout, structure, and user interface. In Appendix 8 the service blueprint can be explored to get the better understanding of the proposal.

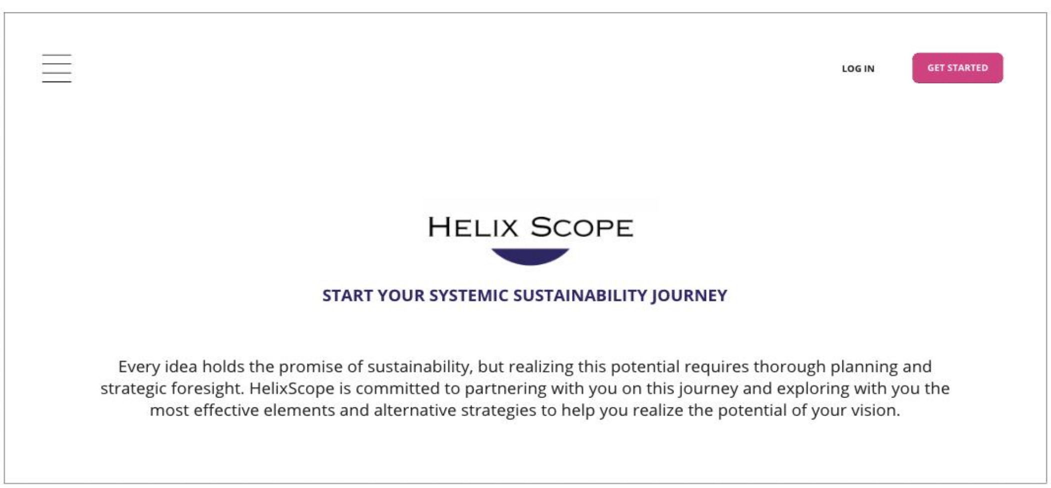

Figure 15: Digital mockup of the landing page of Helix Scope. Source: Author

The platform (see Figure 15) was designed with the following principles in mind:

- **Simplicity**: The interface was intentionally designed to prioritize simplicity, ensuring that users are not overwhelmed by the complexity of the tool. Adopting a minimalist aesthetic, the platform aims to deliver a user-friendly experience.
- **Interactivity**: Recognizing that founders often face challenges when launching new business models, the platform serves as a support system. It fosters idea generation and enables informed decision-making from the outset, promoting interaction with the platform and collaboration among users.

7.3. User journey

The primary users, business owners, are given the opportunity to map out their PSS elements within the platform. They can analyze how these elements are influenced by various sustainability dimensions, determining their priority based on occurrence and criticality. The tool further prompts them to consider alternatives, particularly for elements flagged as red or orange in the assessment.

After establishing a profile on the Helix Scope platform, users receive clear, step-by-step instructions on how to effectively utilize the tool for comprehensive decision-making and sustainability analysis. The platform automatically guides users through the performance indicators in a simple and non-overwhelming manner, ensuring a user-friendly experience despite the tool's complexity.

The platform facilitates the planning process and encourages initiatives ready to be undertaken by first assessing the current state of performance measurement processes, answering the question "Where are we now?". Users are then guided to identify their strategic objectives and corresponding indicators with "Where do we want to go?". Finally, "How do we get there?" evaluates the transition process throughout the entire lifecycle of the offering. This initial stage of the platform not only guides users through these critical steps but also initiates the storytelling process, setting the stage for ongoing engagement and narrative development. The underlying idea of this phase is to ensure that everything makes sense and to provide a foundation for further exploration and refinement in latter steps (see Figure 16).

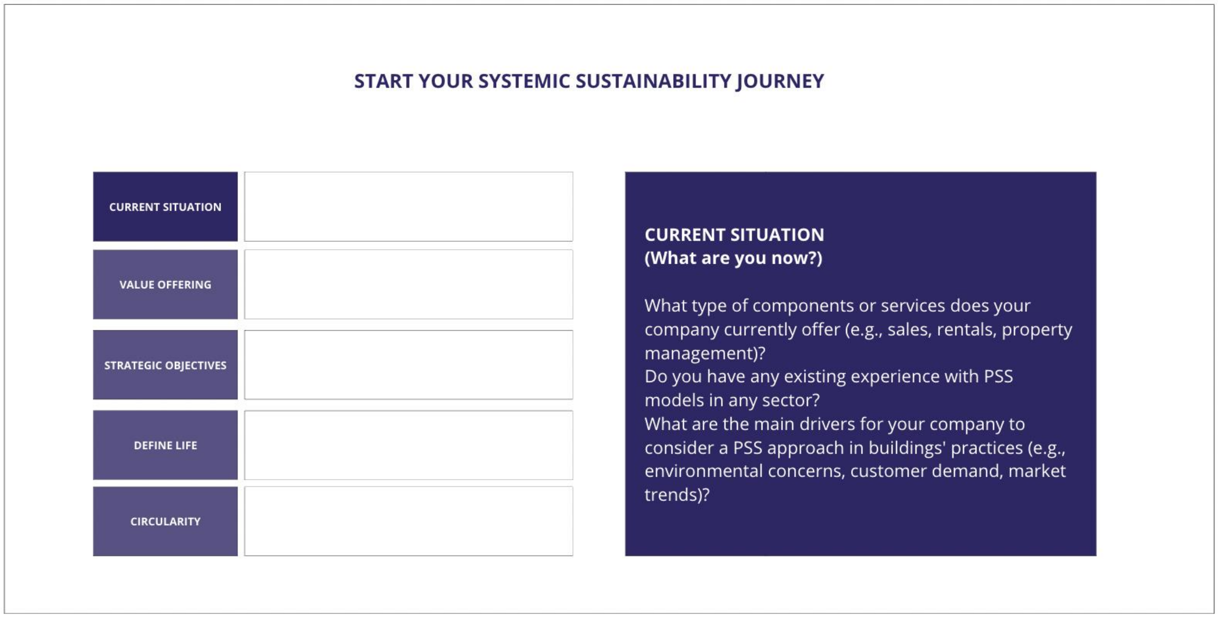

Figure 16: Digital mockup of the performance indicator page of Helix Scope. Source: Author

The system generates a story as a reminder of the business model idea, covering the showed and mentioned points in a narrative form that can be adjusted if needed. This story provides a generic overview as a general reminder. As the following step user has the possibility to start exploring the sustainability dimensions. The system allows users to choose which dimension they would like to start with. This flexibility ensures that the initial steps are aligned with the user's confidence and motivation, fostering a positive start (See Figure 17).

Interconnectedness is one of the core design principles of the platform, aimed at establishing connections between different elements and sustainability dimensions. By highlighting these interconnections, the platform emphasizes the holistic approach necessary for sustainable decision-making later, ensuring that no critical aspect is overlooked.

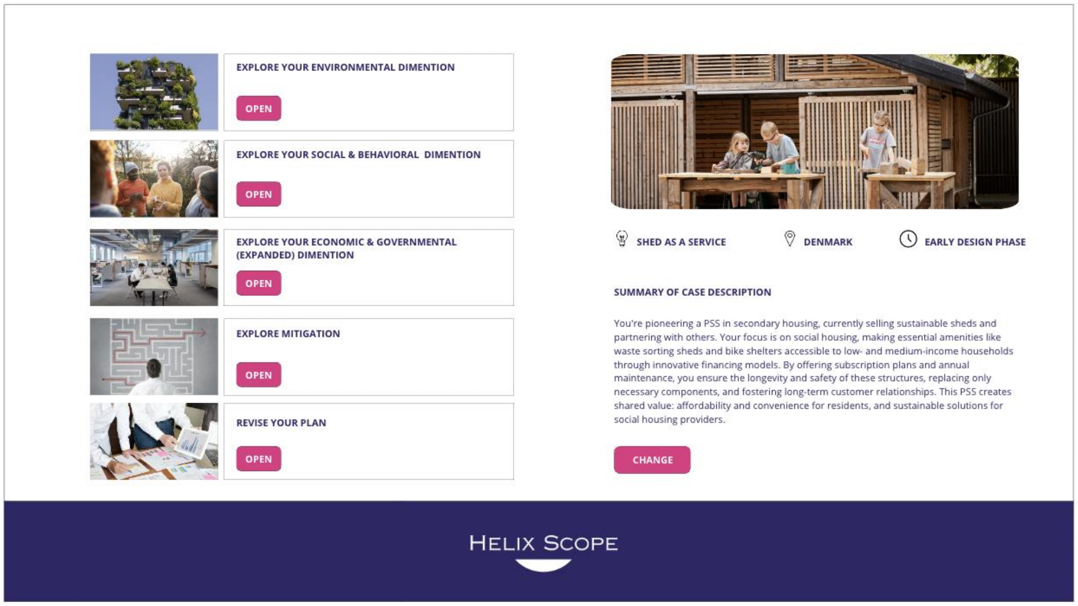

Figure 17: Digital mockup of the main interface page of Helix Scope. Source: Author

The digital platform is offering straightforward industry-related terms, ensuring easy comprehension without unnecessary complexity at first glance (see Figure 18). This approach aims to support user understanding and encourage active engagement with the platform's functionalities.

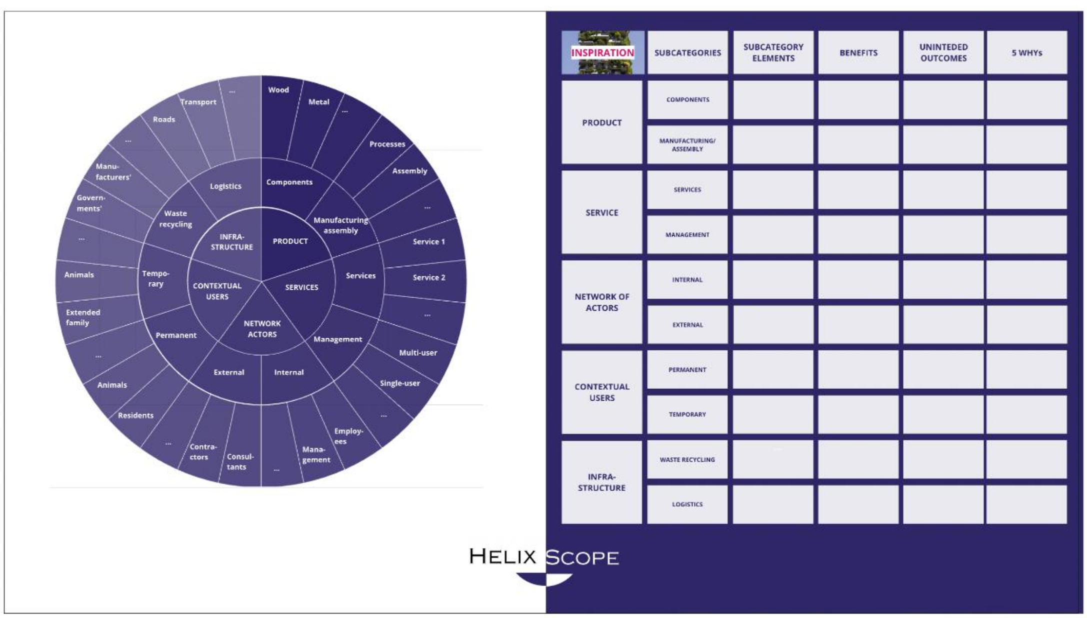

Figure 18: Digital mockup of the discovery of interconnectedness with Helix Scope. Source: Author

On the left side of the screen are examples of keywords for each of the PSS elements and their potential sub-elements on the helix shape. These serve as a prompt for idea generation, while further instructions and examples are provided upon clicking on the sectors, which reveal definitions of the elements and industry-specific examples. This guidance is facilitated by built-in descriptions and AI-powered assistant, leveraging a knowledge base derived from previous research to offer recommendations and support users in their decision-making process. Additional methods of guidance can be explored in Appendix 9. Once the dimensions are mapped, users can proceed with the next step, guiding users through a comprehensive and integrated process. Each part of the tool can be moved between back and forth ensuring that each of the parts is filled and enabling users to mark down another connection that is made during the process.

Companies are encouraged to assess both the positive and negative outcomes of their proposed actions. For this, users are prompted to identify specific benefits and any unintended outcomes resulting from these benefits. The “5Whys” technique is employed as a causal connection finder that helps to reveal the deeper outcomes, as initial finding may not always reflect the reality. In this mockup stage or any subsequent stage, any unknown information can be designated with a "?" symbol to signify uncertainty. This "?" symbol creates a yellow corner in the square it was marked in, indicating that something is unknown and should be revisited later for further examination.

Once all elements of the PSS have been reviewed, the final section of the table shifts focus to mitigation and priority assessment (see Figure 19) Here, companies must evaluate the severity and likelihood of each outcome occurring, laying the groundwork for determining where to prioritize their attention. The goal is to understand which of the areas need the most attention. Brainstorming potential solutions to mitigate identified outcomes is essential especially to the ones marked red or orange indicating the higher urgency. Exploring alternatives and seeking opportunities to balance negative outcomes with positives or if possible potential mitigation. Additionally, the platform encourages further exploration of alternatives from other sources to exchange decision-making. The best alternatives can be marked within the platform as the best possible option setting them priority that the platform recognizes in the revision part.

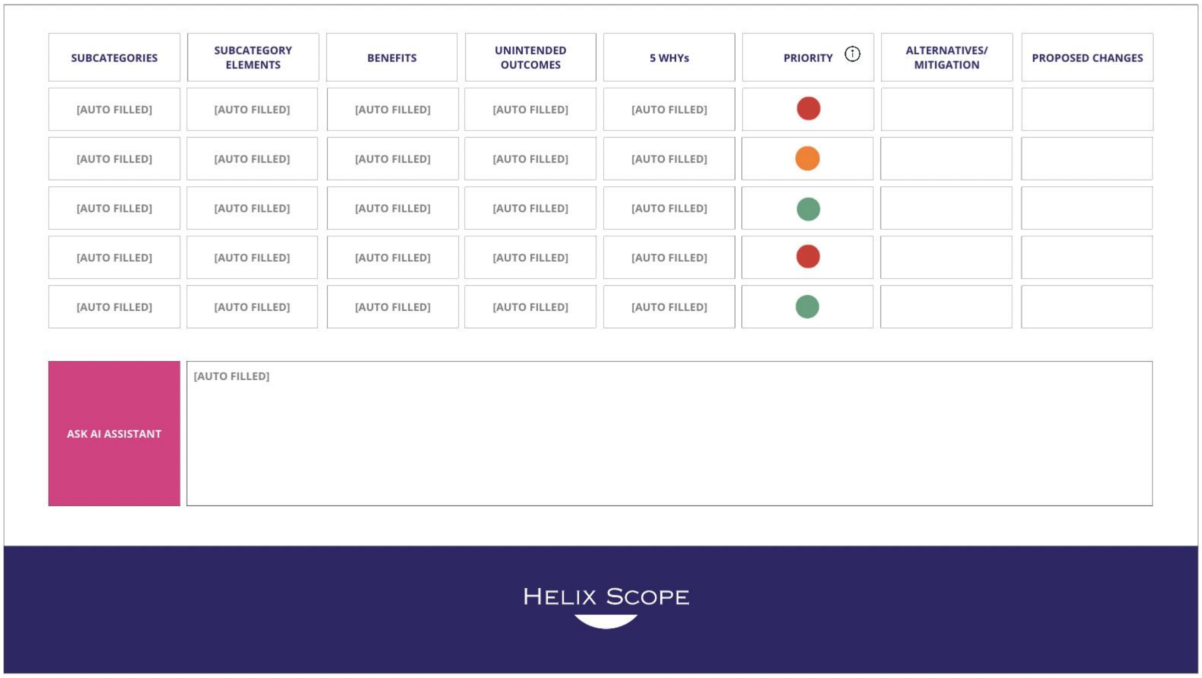

Figure 19: Digital mockup of the mitigation and alternative exploration page of Helix Scope.
Source: Author

As previously mentioned, the platform incorporates built-in descriptions along with an AI-powered assistant to offer guidance on exploration and usage. Drawing from a knowledge base derived from previous research, the assistant provides recommendations to aid users in their decision-making endeavors.

In the revised plan section, the system compiles all the data input from previous sections, particularly focusing on the components, to formulate revised plans. Through a process of analysis and comparison, the system identifies the most optimal options with the help of the user that highlights them for consideration. This view due to the left can be seen in Appendix 10. Users retain the flexibility to delve into the plan and adjust if they encounter discrepancies or acquire new insights during the real-life development process.

7.4. Use case

The company, currently ramping up its production to produce one module per week, aims for greater efficiency through a division of responsibilities. With one team managing on-site operations and another overseeing manufacturing, they are organizing their processes for optimal performance. Being still in the early design phase and navigating various elements, such a company could find support from a solution like Helix Scope. This use case is being presented based on the fourth testing.

Their primary focus is on providing value to social housing associations with limited budgets, a challenge posed by the requirements of the Danish system. Housing associations need to secure funds not only for the initial purchase of secondary housing modular units like sheds but also for subsequent repairs. Given the financial constraints faced by these associations, such an opportunity to get sheds as a PSS could render the operational costs feasible and attainable. Such models enable for instance yearly checkups or additional necessary services. The company changes the parts that cannot be used anymore due to the quality. This long-term vision entails refurbishing sheds as needed over a thirty-year period and facilitating their relocation to new sites. While the plan includes reusing materials whenever possible, practical constraints may necessitate reuse or remanufacturing. Nevertheless, the overarching goal is to minimize waste by repurposing unusable materials for energy or wooden panels, aligning with their commitment to sustainability.

Due to the limited time, only two elements were tested in the assigned time: product (components) and service (services). Upon examining the product, it becomes evident that its components consist of wood, metal, and roofing materials such as filt, cassettes for green roofs, reused tiles, and recycled solar panels. While the company's focus lies predominantly on wood, external suppliers provide metal and roofing elements. As company is building from demolished wood the company is striving to eliminate waste and to have a substantial impact on the built environment and the world in general, however, their primary objective is not only to minimize their own production waste, but also to maximize the maximum utilization of existing waste from secondary sources.

However, a limitation arose with the topic of roofing materials. Filt as a method makes the underlying wood non-reusable after 30 years, necessitating incineration. Delving into the causal relationships and idea generation to finding alternatives or ways to balance it out "5 Whys" were being investigated:

- Why? It is a common practice.
- Why? Difficulty to find alternatives in some cases.
- Why? Hard to find reusable cladding that they prefer to use.
- Why? Lack of collaboration partners.
- Why? Industry is still changing.

The company is already using green roofs and sourcing reusable cladding, as well as fostering collaboration with partners. While some in this problematic area has been noticed, there is still looked improvement area with roofing filt. Seeking alternatives with that material could bring improvements.

A similar occurrence was noticed within the service category. After delving into the section, the need for mitigation of behavioral effects stood out. This emphasized the potential need to establish contracts prioritizing the reduction of behavioral impacts from contextual users. This includes fostering relationships through trust and education to ensure that modules are used in the intended way. This action also aligns well with their business model that states that while circularity and sustainability are their fundamental values, the company also aims to drive a significant transformation in the behaviors of various stakeholders, including users, customers, industry players, and society.

The tool highlighted key areas of concern with in the two areas able to be tested. They underscored the tool's role in pushing the owners to adopting a critical perspective, encouraging stakeholders to explore potential weaknesses and take proactive approaches to mitigation. By encouraging a thorough examination of potential issues, the tool empowers them to adress issues more effectively and implement then a proactive approach to ensure an optimal outcome.

7.5. Value proposition

In the complex ecosystem like the built environment, decision-makers in early design phases can face difficulties navigating uncertainties while having a goal of striving for optimal outcomes, as discussed in the theoretical background. Hence, Helix Scope has multiple value propositions if offers.

Avoiding sole reliance on intuition: the digital platform serves as a guiding tool, offering support to business owners that goes beyond intuition. Decision-makers can leverage gained insights to make informed choices independently, minimizing the risks associated with relying solely on gut feelings.

Interactivity and support: Through interactive feature of an AI assistant and instructions, user can share their knowledge, seek advice, and collaborate technolgy that looks for connections, ensuring they have the support may need to navigate through complexities.

Cost-effective solution: At times when the resource availability can be limited, the platform offers a free of charge guidelines, aiming to lessen expenses for users while providing valuable decision-making support.

Systematic approach: The platform adopts a systematic approach to decision-making. By guiding users through structured processes and providing comprehensive tools, it ensures that every aspect of a decision is carefully considered and analyzed, leading to more robust outcomes.

8. DISCUSSION

This chapter discusses this thesis's contribution to the topic and serves as an acknowledgement for other tools relevant to it (section 8.1). Also, the limitations of the work are described (section 8.2), and further research directions are proposed for future research (section 8.3).

8.1. Originality and contribution

Several existing tools address aspects of sustainability and circular economy practices within different contexts. Although these are not specifically meant for built environment lessons can be drawn from them. For instance, Sarancic et al. (2022) introduced the BESST tool, designed to screen sustainability dimensions during the early stages of design. Their methodology involves estimating opportunities through cost-benefit evaluations, offering insights into potential problematic areas needing intervention (Sarancic et al., 2022). Additionally, Gustafsson & Harild (2021) focused on mitigating unsustainable behaviors in business-to-consumer contexts, leveraging principles of Design for Sustainable Behavior to develop targeted strategies for behavioral change. Meanwhile, Metic & Pigosso (2022) contributed to the discourse by establishing a conceptual framework for understanding the RE associated with circularity initiatives. Their work shed light on the multifaceted impacts of circularity efforts, delineating potential areas of influence and intervention. Building upon this foundation, Das et al. (2023) honed their focus on circular RE, refining existing methodologies and proposing design cards to specifically target these phenomena. However, a notable limitation of their approach lies in the reliance on subjective assessments by practitioners and little on the literature discovery side during the initial brainstorming phase, which may introduce biases affecting subsequent mitigation efforts.

However, it's noteworthy that the tools developed were only able to address certain parts of the sustainability landscape, with a limited focus on mitigation. While these tools offer valuable insights into identifying issues within the sustainability landscape, they fall short when it comes to facilitating a holistic proactive solution. This work hence focused on a more comprehensive framework that would help translate the previously done research into a practical approach.

This study contributes to the existing body of literature by exploring the challenges prevalent within the building sector and subsequently devising a screening tool to confront these challenges within the early design phase. The tool developed represents a development from existing methodologies by facilitating a more comprehensive analysis and strategic deliberation, particularly concerning the mitigation of unwanted outcomes. While the primary focus lies on aiding companies during their early design phases, the tool's inherent flexibility ensures its applicability across diverse stakeholders within the housing as temporary modular buildings can be seen as part of this domain, thereby enriching their understanding of potential outcomes and enhancing the decision-making process.

By adopting a holistic approach, the tool empowers stakeholders to thoroughly explore the intricacies of sustainability dimensions and evaluate the impacts of their decisions across various aspects. This thorough analysis promotes independence, especially in resource-constrained situations, and encourages informed decision-making.

8.2. Limitations

The study's main limitation lies in its small sample size. With a response rate of only 2.5%, the findings may not accurately represent the broader population the research intended to investigate. While companies also expressed interest in participating, their busy schedules ultimately prevented them from doing so. To mitigate this, efforts were made to ensure diverse representation across different construction sectors. Additionally, the qualitative nature of the research implies findings that are generalizable to the specific context of the study, rather than universally applicable.

Another challenge was the scattered nature of the research on this topic. The search strategy employed hence for existing literature may have inadvertently excluded relevant studies. The use of keywords could have resulted in missing studies that used different terminology or phrasing. Similarly, relying solely on titles and abstracts for initial screening may have led to the exclusion of relevant research that was not fully captured in those sections.

Finally, thematic analysis using MAXQDA, while a valuable tool, inherently involves subjective judgments during data interpretation. The researcher's decisions about what constitutes relevant themes and which interview segments to include could introduce bias. Furthermore, the study's reliance on self-reported data gathered through conversations introduces the possibility of unintentional misstatements or different recollections based on personal interpretations.

8.3. Future research directions

A crucial future research direction involves expanding the sample size utilized in this study to improve its generalizability across the broader business landscape within the buildings' sector. Enlarging the participant pool to encompass a more diverse array of stakeholders will enable researchers to obtain a more nuanced understanding of the effects emanating from PSS implementation.

While the present study focused on user experiences and perceptions, forthcoming research should embark on a longitudinal examination to assess the tool's efficacy in achieving its intended objectives. This could entail deploying the tool within real-world industry contexts to systematically evaluate its performance and iteratively refine its design and functionality, particularly within the B2B2C ecosystem. Additionally, further investigation into the integration of PSS within the housing sector is warranted, particularly regarding the alignment of company strategies with user behaviors, which emerged as a notable gap during the interviews.

Recognizing the multilevel dynamics inherent in the B2B2C framework, future research should explore strategies for more effectively engaging end users throughout the development and implementation phases. By integrating end user perspectives into the research and development process, companies can tailor their offerings to better align with the specific needs and preferences of target audiences, thereby enhancing overall user experience within the B2B2C ecosystem. Addressing the current gap in incorporating end-user perspectives will be crucial in fostering a more inclusive and user-centric approach to PSS implementation within the building sector.

Another important avenue for future research would be to conduct multi-case studies aimed at exploring various mitigation theories in greater depth. By extending the duration of these studies, researchers can delve into the intricacies of different mitigation approaches across multiple cases, providing a more comprehensive understanding of their effectiveness and applicability within the building sector.

9. SUMMARY

The construction and demolition industry's significant resource consumption and pollution output presents a pressing challenge, especially due to the projections of continued growth. This linear industry's practices, characterized by resource depletion and waste generation, necessitate a shift towards more sustainable strategies.

This growing need for sustainability has prompted exploration into new approaches within the industry. One such strategy is the adoption of the circular economy and PSS. PSS moves away from traditional product-centric approaches by focusing on integrated service models that add value throughout a product's lifecycle, not just during sales. Despite increasing interest in PSS there is still limited understanding of its outcomes within the context of buildings, using temporary modular buildings as an example. This research aimed to identify elements and potential problem areas for companies within the industry to propose a holistic approach to address these challenges.

The construction industry's complexity and maturity, coupled with the involvement of many stakeholders, pose significant challenges. The study emphasizes the importance of considering various dimensions, including economic, environmental, societal, technological, and governmental factors. Through semi-structured interviews and co-creation workshops, the research adopts a holistic perspective to explore the systemic implications of PSS within the built environment, incorporating real industry insights. Specifically, the study identifies critical elements for companies adopting sustainable PSS models, including product, service, infrastructure, network of actors, and users. Furthermore, it highlights the need to overcome inertia and encourage companies to make informed decisions based on holistic analysis rather than intuition alone.

These theoretical findings were translated into practical tools for companies in the early design phase. To bridge the knowledge gap and support decision-making, this study introduces Helix Scope—a strategic tool that facilitates holistic mapping and understanding of the business environment. By considering all PSS elements and sustainability dimensions, Helix Scope empowers users to make well-informed choices that prioritize sustainability across all aspects of their business. Additionally, its integration with an AI assistant enhances decision-making by analyzing existing content and suggesting additional considerations, thereby reducing reliance on limited experience and intuition.

The objectives set forth in Chapter 1 have been successfully achieved. The study aimed to examine the potential impacts of implementing PSS in the sector, alongside establishing evaluation criteria to aid companies in addressing these effects proactively. This was accomplished through a comprehensive analysis of existing literature and gathering input from companies regarding their current challenges, supplemented by common effects associated with PSS. Additionally, valuable insights were garnered through interviews with industry experts, providing firsthand perspectives on the utilization of PSS and its effects within the sector.

10. KOKKUVÕTE

Ehitus- ja lammutustööstuse märkimisväärne ressursitarbimine ja saaste tekitamine on pakiline väljakutse, eriti jätkuva kasvu prognooside tõttu. See lineaarne tööstusharu, mida iseloomustab ressursside ammendumine ja jäätmeteke, nõuab üleminekut säästvamate strateegiate poole.

See kasvav vajadus jätkusuutlikkuse järele on ajendanud tööstust uurima uusi lähenemisviise. Üks selline strateegia on ringmajanduse ja toote-teenuste süsteemide kasutuselevõtt. Toote-teenuste süsteemid liiguvad eemale traditsioonilistest tootekesksetest lähenemistest, keskendudes teenusemudelitele, mis lisavad väärtust toote elutsükli jooksul, mitte ainult müügi ajal. Vaatamata kasvavale huvile selle mudeli vastu, on selle mõjudest hoonete kontekstis, näiteks ajutiste moodulmajade kasutamisel, endiselt piiratud arusaam. Käesolev lõputöö uurib elemente ja potentsiaalseid probleemkohti, et pakkuda holistilist lähenemist probleemkohtade adresseerimiseks.

Ehitustööstuse keerukus ja küpsus koos paljude sidusrühmade kaasamisega kujutavad endast olulisi väljakutseid. Lõputöö rõhutab vajadust arvestada mitmesuguste dimensioonidega, sealhulgas majanduslike, keskkonna-, sotsiaalsete, tehnoloogiliste ja valitsuslike teguritega. Semi-struktureeritud vestluste ja kaasloome töötubade kaudu luuakse lõputöö raames terviklik perspektiiv, kuidas uurida toote-teenuste süsteemide soovimatuid tagajärgi ehitussektori keskkonnas, kaasates spetsialistide reaalseid vaateid. Lõputöös määratletakse jätkusuutliku toote-teenuste süsteemide mudeli kasutuselevõtuks kriitilised elemendid, sealhulgas toode, teenus, infrastruktuur, osalejate võrgustik ja kasutajad. Lisaks rõhutatakse vajadust ületada inertsus ja julgustada ettevõtteid tegema teadlikke otsuseid, mis põhinevad terviklikul analüüsil, mitte ainult intuitsioonil.

Need teoreetilised järeldused on tõlgitud praktilisteks vahenditeks ettevõtete jaoks varases projekteerimisetapis. Teadmiste puudujäägi ületamiseks ja otsuste tegemise toetamiseks tutvustab käesolev lõputöö Helix Scope'i – strateegilist vahendit, mis hõlbustab ärikeskkonna terviklikku kaardistamist ja mõistmist. Võttes arvesse kõiki toote-teenuste süsteemi elemente ja jätkusuutlikkuse dimensioone, annab Helix Scope kasutajatele võimaluse teha hästi informeeritud valikuid, mis seavad jätkusuutlikkuse prioriteediks kõigis nende ettevõtte aspektides. Lisaks suurendab selle integreerimine tehisintellekti assistendiga otsuste tegemist, analüüsides olemasolevat kirjutatud teksti sisu ja pakkudes täiendavaid kaalutlusi, vähendades seeläbi sõltuvust piiratud kogemustest ja intuitsioonist.

Peatükis 1 sätestatud eesmärgid on edukalt saavutatud. Uuringu eesmärk oli uurida toote-teenuste süsteemi rakendamise võimalikke mõjusid sektoris ning luua hindamiskriteeriumid, mis aitaksid ettevõtetel ennetavalt nende mõjudega tegeleda. See saavutati olemasoleva kirjanduse põhjaliku analüüsi ja ettevõtetelt nende praeguste probleemide kohta sisendi kogumise kaudu, mida täiendati toote-teenuste süsteemidega seotud ühiste mõjude hindamisega. Lisaks saadi väärtuslikke teadmisi intervjuudest valdkonna ekspertidega, mis andsid esmapilgul ülevaate toote-teenuste süsteemi kasutamisest ja selle mõjudest sektoris.

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LIST OF FIGURES

LIST OF TABLES

APPENDICES

APPENDIX 1: Structure for the interviews. By the author

Interview Script

Introduction: Hello, I appreciate you taking the time to join me for this conversation. My name is Heleri Kallaste, I am a Master of Science student at Tallinn University of Technology, and I am studying Design and Technology Futures. I am currently in Denmark and with external supervisors we are reflecting on the question of how to make construction more circular. Study results will help provide insight to how to support actors within the industry.

The interview will take about an hour.

Once again, thank you for agreeing to participate in an interview. Your willingness to participate is appreciated highly. During the interview we will reflect on topics like circular economy, unwanted outcomes, and organizational learning processes.

May I record our conversation? It will help me to go back to our conversation and analyze the answers provided in more depth. If I decide to use any quotes from our conversation, I'll certainly verify them with you beforehand.

It's essential to note that there are no right or wrong answers; I'm genuinely interested in your personal perspectives. Should any question make you uncomfortable, feel free to decline answering.

[recording starts]

[Here are the predetermined questions used for interviews. Ones marked in gray were preliminary ideas where the conversation may take, yet may not]

Introductory questions:

- Please introduce yourself and your work at [company] briefly.

PSS:

- How do you understand Product-Service Systems (PSS) in the context of your company?
- What solutions do you offer that combine products and services at the same time?
- How you perceive the value you create?
- How do the products and services you offer add value to the user?

Sustainability dimensions:

- Can you describe your company's approach to sustainability and circularity?
- What are the perceived effects of adopting PSS?
    - What effects arise from an economic perspective?
    - What effects arise from an environmental perspective?
    - What effects arise from a social perspective?
- Considering the environmental, economic and social dimensions, which dimension has the greatest emphasis from the company's perspective?
- How do you measure the results of the economic, environmental and social impacts?
- How have you reduced the environmental impact of your product/service over time? How?
- What are the perceived negative outcomes of adopting PSS?
    - What negative economic effects have you perceived?
    - What negative economical effects have you perceived?
    - What negative social effects have you perceived?
- What unexpected results have you encountered that were not initially anticipated?
- What measures does your company take to mitigate potential unwanted outcomes associated with the adoption of PSS?
- How do you minimize unwanted outcomes?
- Have you over time improved the product or production based on unwanted outcomes? What have been the key improvements and the key influences?
- How do you measure in your company the viability and competitiveness of your PSS offering? How do you stay competitive?
- How do you understand the concept of a circular economy?
- What circular economy strategies does your company implement?

- What are the important issues for your company regarding the implementation of the circular economy principle?
- What are your future plans for the development and implementation of PSS models in your company?

Social sustainability:

- Are you aware of positive changes in people's behavior patterns that have occurred while choosing your solution?
- Have there been cases where customers have used your products in unexpected ways?
- How have you reacted to unexpected product uses?
- Have you changed your products because of unexpected product uses?
- What unexpected results have you encountered that were not initially anticipated?
- How do you ensure satisfaction?
- Still seeing social groups that don't want to tap your services? Which ones and do you also know the reasons?
- What are you doing to increase clients' awareness and acceptence?
- How do you involve customers in the development and implementation of your product? How have you used customer feedback to improve your production processes?
- What regulative norms shape your product offering?

Implementation of PSS:

- What are the major challenges in the implementation and day-to-day management of your product?

Product platform (additional)

- Do PSS help you to operate more (resource-) efficient?
- Do PSS support save materials / reusing materials?
- Do you work with standardization and / or modularization?

That’s all from my side, would you like to add something from your side?
Thank you once again! Have a lovely day!
(if applicable) See you soon at the workshop!

APPENDIX 2: Structure for the co-creation workshops. By the author

Interview Script

Introduction: Hello, I appreciate you taking the time to join me once again. How have you been?

The workshop will take about an hour.

Once again, thank you for agreeing to participate in an interview. Your insights are highly valued to guide the further development of the practical approach. The workshop's objective is to assess the prototype, which was informed by research, to determine its applicability and usefulness in the industry. By doing so the aim is to avoid creating something that does not potentially find usage.

May I record our conversation? This will help me revisit our conversation and analyze the answers provided to make alterations.

[recording starts]

[Here are the guidelines used for prototype testing.]

Ease of Use:

- I would like to start by understanding your initial experience with the tool.
- How easy did you find it to learn how to use the prototype?
    - (if necessary) Were there any specific features that were intuitive?
    - (if necessary) Were there any special features that were confusing?
    - (if necessary) How would you rate the clarity of the prototype?
- Did you find the tool user-friendly and easy to navigate?
- [While they answer, paying attention to their body language and interactions]
- Did you encounter any difficulties understanding what the tool does or how to use its functionalities? If yes, please elaborate on specific examples.

- Would you start using the tool?

Workflow Integration:

- Now, let's talk about how the tool would fit into your design process.
- Can you briefly describe your typical workflow for tackling product related problems?
- Based on your workflow, how well do you think this prototype could integrate?
    - (if necessary) Where in your workflow could you see this tool being most helpful?

Time Efficiency:
- Did you feel the tool helped you complete tasks efficiently?
- Were there any parts of the tool that slowed you down?

Additional Exploration (if necessary):

- Can you tell me about the metrics or data points you typically use to evaluate your offering?
- Would something else make sense? Would you change something?

That’s all from my side, would you like to add something from your side?
Thank you once again! Have a lovely day!

APPENDIX 3: Overview of the outcomes associated with buildings. Source: foundation from Ghafoor et al 2023, modified and supplemented by author

Table 3: Overview of the outcomes associated with buildings. Source: foundation from Ghafoor et al 2023, modified and supplemented by author

Driving force	**Approach**	**Enabling activity**	**Excepted outcome**	**Unintended outcome**	**Source**
Legislation	•Local and national standards	•Local and national legislation •Action plans	•Compliance with the regulations •Positive outcomes	•Companies are reluctant making changes, wait until legislation comes (if comes)	Interviewee Y1, Y6
Governance	•Management structure and action plans	•Clear goals •Ethical management •Transparent compensation system •Anti-corruption policies	•Healthy indoor climate •Focus on employees	•Leaning on intuition •Leaning on experience •Lower realization of benefits	PwC, n.d.; Murray et al, 2e015
Maintenance	•User centered •Use secondary, upcycled, healthy, local, and bio-based materials •Passive •Flexibility •Services	•Collaboration and co-creation •Use of community/local capacity •lightweight materials	•Reduced material use •Reduced operational energy and water use •Reduced and repurposed waste •Reduced GHG waste •Jobs •Increased user/community support •Physically fewer exhausting repairs due to lightweight materials	•Some still goes to landfill •Low tenant emotional affinity •Limited control over usage phase •Increased consumption •Injuries due to heavy machinery	van Stijn & Gruis, 2019; Houvila et al., 2019; Mazur, 2021; Ghafoor et al., 2023; Interviewee 5;

Reuse	•Use of secondary, upcycled, healthy, local, and bio-based materials •Demountable •Use lightweight material	•Collaboration and co-creation •Modularity •Accessible building design •Digital technologies	•Collaboration and co-creation •Modularity •Accessible building design •Digital technologies	• Reduced material use • Reduced C&D waste • Reduced GHG emissions • Reduced maintenance cost • Reducing packaging use	Zairul et al., 2018; Salingaros, 2019 ; van Stijn & Gruis, 2019; Fatourou-Sipsi & Symeonidou, 2021; Köhler et al., 2022; Ghafoor et al., 2023;
Refurbish Remanufacture	•Desmountable, accessible •Use of less parts •Use durable materials	•Repair instructions •Accessible connections •Optimized processes •Live monitoring •Modular construction, simplicity	•Increased quality	•Build-to-last, harder to break down •Use of more energy down • Buying material back, company has less motivation to consider this an issue as fiancialy they gain	Murray et al., 2015; van Stijn & Gruis, 2019; Ghafoor et al., 2023;
Adaptability	• Flexible/ expandable •User-centered •Use durable, healthy, and bio-based materials •Demountable	•Collaboration and co-creation •Modularity •Accessible building design •Digital technologies	•Reduced material use •Reduced C&D waste •Increased quality, control, and comfort •Increased user, community support •Social aspects such as health, wellbeing, and inclusiveness •Jobs	•Unprecise data •Refurbishment time •Accessibility •Uncertainty of modular elements indicators •Tenant behavior •Changing needs •Readiness to use • Culture, surroundings	Mont, 2004; van Stijn & Gruis, 2019; Geldermans et al., 2019; Cambier et al., 2021; Çetin et al., 2022; Ghafoor et al. 2023;

Low cost	•User centered •Use secondary, upcycled, healthy, local, and bio-based materials •Passive •Flexibility	•Collaboration and co-creation •Use of community/local capacity	•Reduced material use •Reduced operational energy and water use •Reduced and re-purposed waste •Reduced GHG waste •Jobs •Increased user/community support	•Some still goes to landfill •Low tenant emotional affinity •Limited control over usage phase •Increased consumption	van Stijn & Gruis, 2019; Mazur 2021; Ghafoor et al. 2023
Ownership	•User centered •Use quality materials	•Emotional desirability, aesthetic updates •Design for unintended use	•Trust •Durable •Lessen unsustainable use, lessen carelessness, equality (gender, racial, religious, financial, etc), diversity	•Tenant behavior and carelessness •Shorter product life cycle	Murray et al., 2015; Geldermans et al., 2019; van Stijn & Gruis, 2019; Ghafoor et al. 2023; Ackermann & Tunn, 2024;

APPENDIX 4: Summary of co-creation workshops. By the author

Table 4: Summary of co-creation workshops. Source: Author

Goals	**Co-creation workshop**	**Evaluation**
Evaluation of applicability and usefulness. Main questions How does the tool integrate into existing workflows? Will it help the evaluation processes? Does the tool assist a company in evaluation of the effects (including negatives)?	W1:Y8	Positive aspects: • Helps to screen thoroughly • Alternative use as information sharing • Gives structure • Would help to identify stakeholders Negative aspects: • Some sustainability dimensions are repetitive – extra work • Tallness scares
	W2:Y4	Positive aspects: • Helps to screen thoroughly • Gives structure • Evaluation of lifecycle • Dimensions are now logical Negative aspects: • LCA expressed statically • Lacking the ability to think about performance • More details needed
	W3:Y8	Positive aspects: • Helps to screen thoroughly • Pushes to discover cause-and-outcome connections Negative aspects: • The wording is not industry standard • Too little detailed • Setting the stage is missing – what to evaluate
	W4:Y4	Positive aspects: • Detailed • Pushes to think critically Negative aspects:

		• Helix shape keywords should be rearranged. For instance, contextual users/network should have first permanent and then temporary users

APPENDIX 5: Guidelines created with inspiration from industry reporting practices. Source: foundation from PwC n.d, modified and supplemented by author

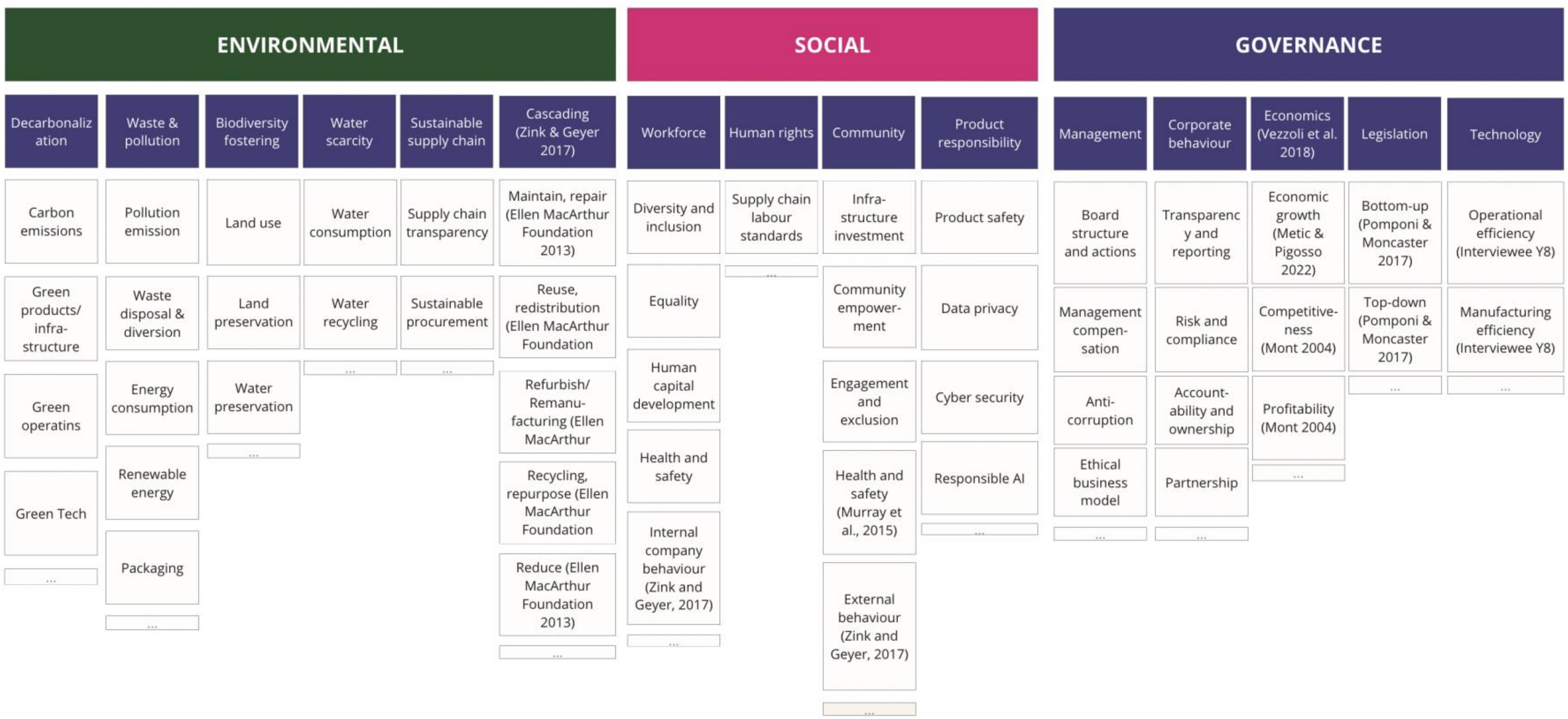

Figure 20: Guidelines created with inspiration from industry reporting practices. Source: foundation from PwC n.d, modified and supplemented by Author

APPENDIX 6: Risk assesment

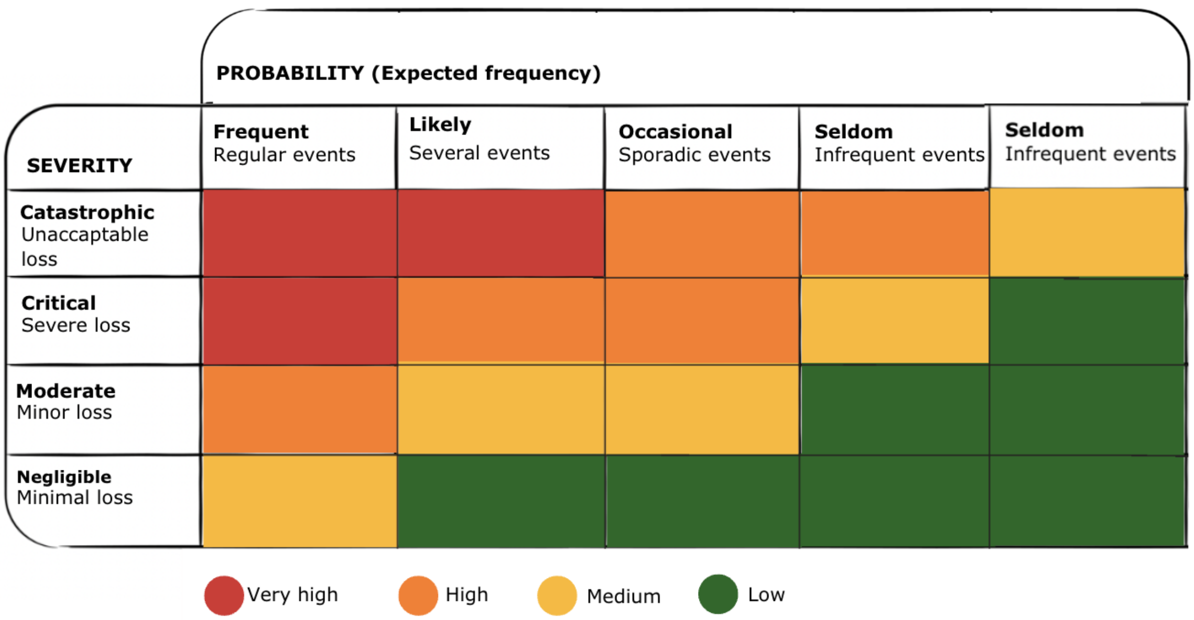

Figure 21: Risk assesment. Source: Pessenden 2023.

APPENDIX 7: Systems’ mapping for Helix Scope by author

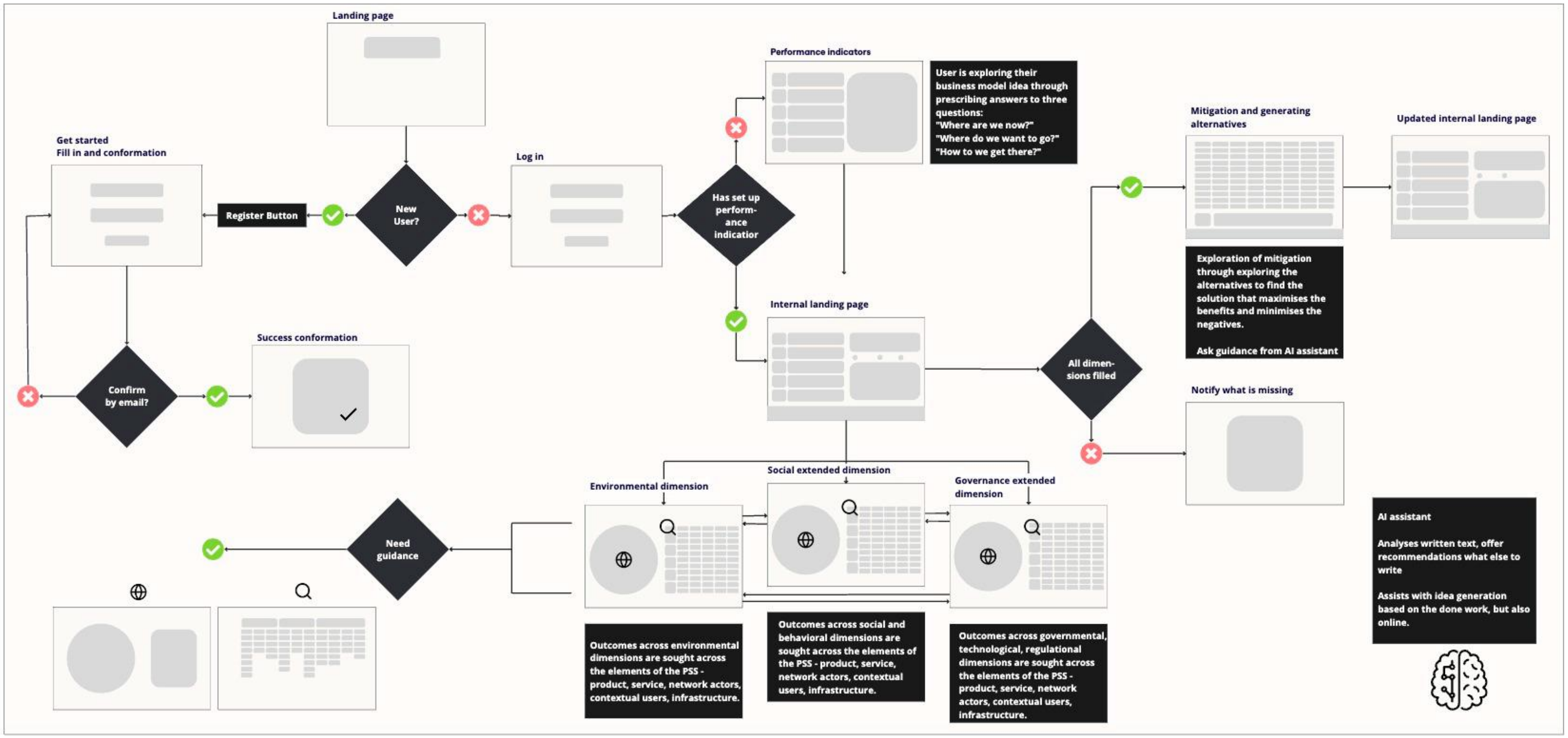

Figure 22: Systems’ mapping for Helix Scope. Source: Author

APPENDIX 8: Service blueprint for Helix Scope by author

	Regisration	Performance indicators	Make a decision where to start	Map sustainability dimension	Mitigate unwanted outcomes	Refined business case
User Goal	Sign up for the platform to start using the holistic approach to conscious independent decision-making.	Reiterate initial business idea and set performance indicators that are the foundation for it all.	Start with the dimension based on familiarity	Understand how various dimensions (economic, social, behavioral, governance, technological, regulation) are interconnected with PSS elements (product, service, network actors, contextual users, infrastructure).	Understand what unwanted outcomes exist, their priority, and brainstorm mitigation strategies or alternatives.	Get an overview of the refined business model and determine the way forward.
User Action Actions done by the user	Access the registration page. Fill out the registration form. Agree to terms and conditions. Submit the form. Confirm their email.	Access the performance indicators setup page. Answer the following questions: "Where are we now?" "Where do we want to go?" "How do we get there?"	Pick a dimension to start with. Modify the business model story if needed.	Read instructions and guides. Fill out the economic dimension by marking components within each PSS element. Identify and document intended benefits of each element. Examine unintended outcomes to discover causal relationships. Use the "5 Whys" technique to explore deeper. Mark unknowns with "?". Optionally accept AI assistance for recommendations.	Identify and list unwanted outcomes. Understand the criticality of each outcome. Prioritize outcomes based on severity and likelihood. Brainstorm alternatives and mitigation strategies. Mark unknowns with "?". Mark preferred alternatives. Optionally use AI for further brainstorming.	Discover the newly created business model. Examine each dimension separately. View the AI-generated story summarizing the business model. Assess the AI-generated story for coherence. Export the results as a file.
Front Stage Action Action can be seen by user, operated by the system	Display registration form. Validate input data in real-time (e.g., check if the email is properly formatted). Display terms and conditions. Confirm submission and notify user about confirmation email. Redirect user for further setup.	Display the performance indicators setup page. Guide the user through the process: Display input boxes for each question. Offer explanations and examples. Confirm inputs and provide a summary. Suggest additional performance indicators using AI analysis. Use AI to offer recommendations in gray text.	Display landing page with all dimensions. Show AI-generated business story. Allow dimension selection. Enable modifications to the business model story.	Provide detailed instructions. Display interactive interface for marking components within each PSS element. Show explanations and guides on hover/click. Showcase yellow corners where "?" has been marked. Use AI to offer recommendations in gray text. Guide user through the "5 Whys" process.	Provide an interface for listing unwanted outcomes. Offer tools to assess criticality (severity and occurrence). Display options for brainstorming alternatives. Provide AI assistance for idea generation. Allow users to mark preferred alternatives and finalize choices.	Display refined dimensions of the business model. Provide an interface to view and explore each dimension separately. Show the AI-generated business case story. Offer an option to export the business case story and other results as a file.
Back Stage action Actions user is not able to see, supports the experience	Generate and display form from server. Perform server-side validation. Send terms and conditions from database. Store registration details in database. Send confirmation email. Log registration attempt. Initiate welcome sequence for setup.	Retrieve and display the setup page from the server. Monitor and store user inputs. Use data management systems to securely handle information. Analyze inputs with AI to suggest additional indicators. Continuously update database with new examples and explanations. Generate a business model story. Store user inputs and preferences securely.	Generate and display landing page. Retrieve and display AI-generated business story. Manage user selections and modifications. Store and update data securely.	Retrieve and display detailed instructions from the server. Monitor and store user inputs in real-time. Generate yellow corners where "?" is marked. Use AI to analyze inputs and suggest additional considerations. Store data securely and analyze for patterns and connections. Update database with new insights and findings.	Retrieve and display the unwanted outcomes interface from the server. Analyze inputs and assess criticality using predefined metrics. Use AI to generate and suggest alternative solutions. Store user inputs and preferences securely. Continuously update the database with new insights and suggestions.	Generate the business case story based on user inputs and refined dimensions. Manage and store data securely. Generate a detailed report for export.

Figure 23: Service blueprint for Helix Scope. Source: Author

APPENDIX 9: Additional ways of guidance Helix Scope by author

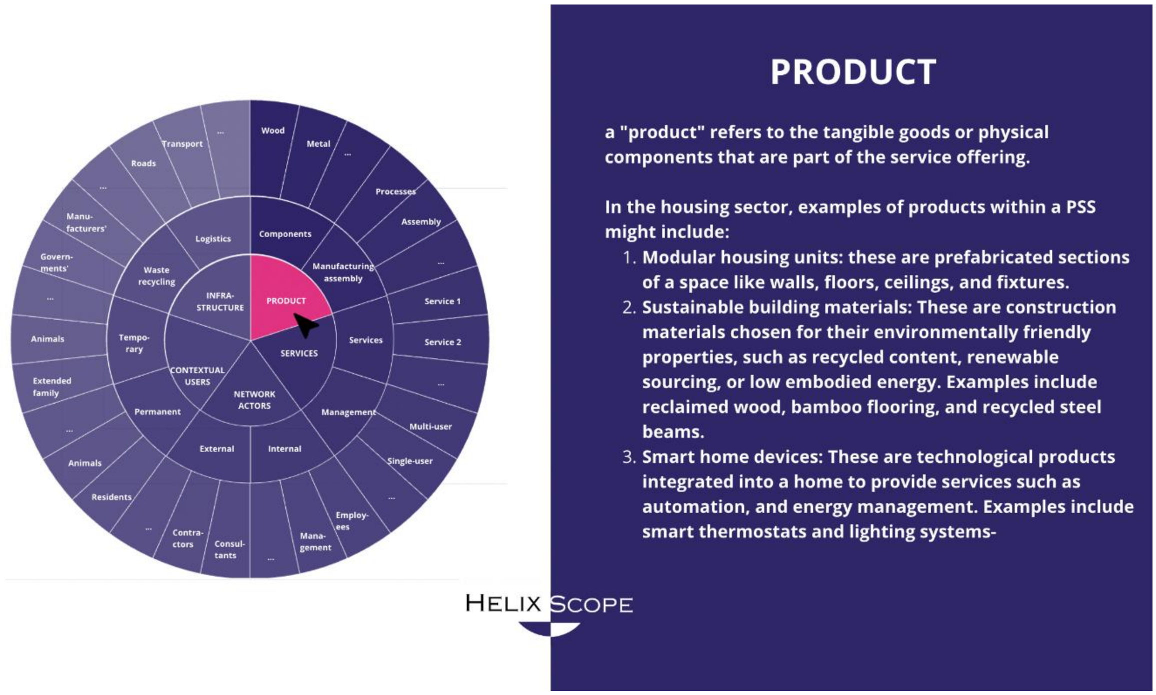

Figure 24: Additional way of guidance Helix Scope (1). Source: Author

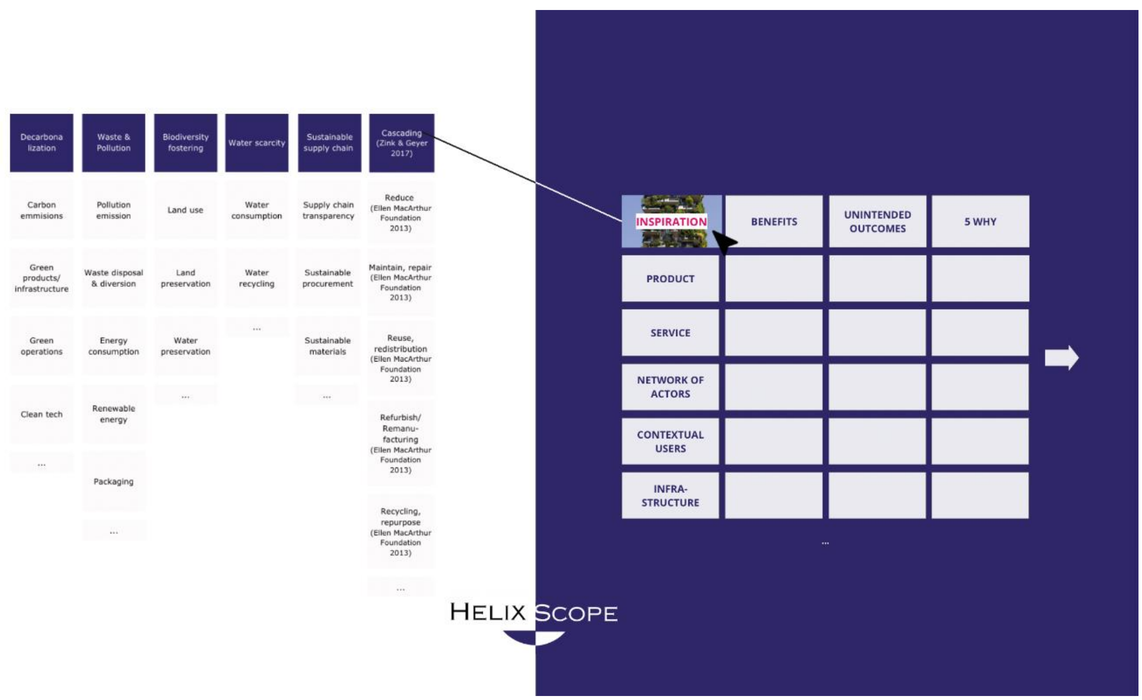

Figure 25: Additional way of guidance Helix Scope (2). Source: author

Figure 26: Additional way of guidance Helix Scope (3). Source: Author

APPENDIX 10: Revised business proposal in Helix Scope by author

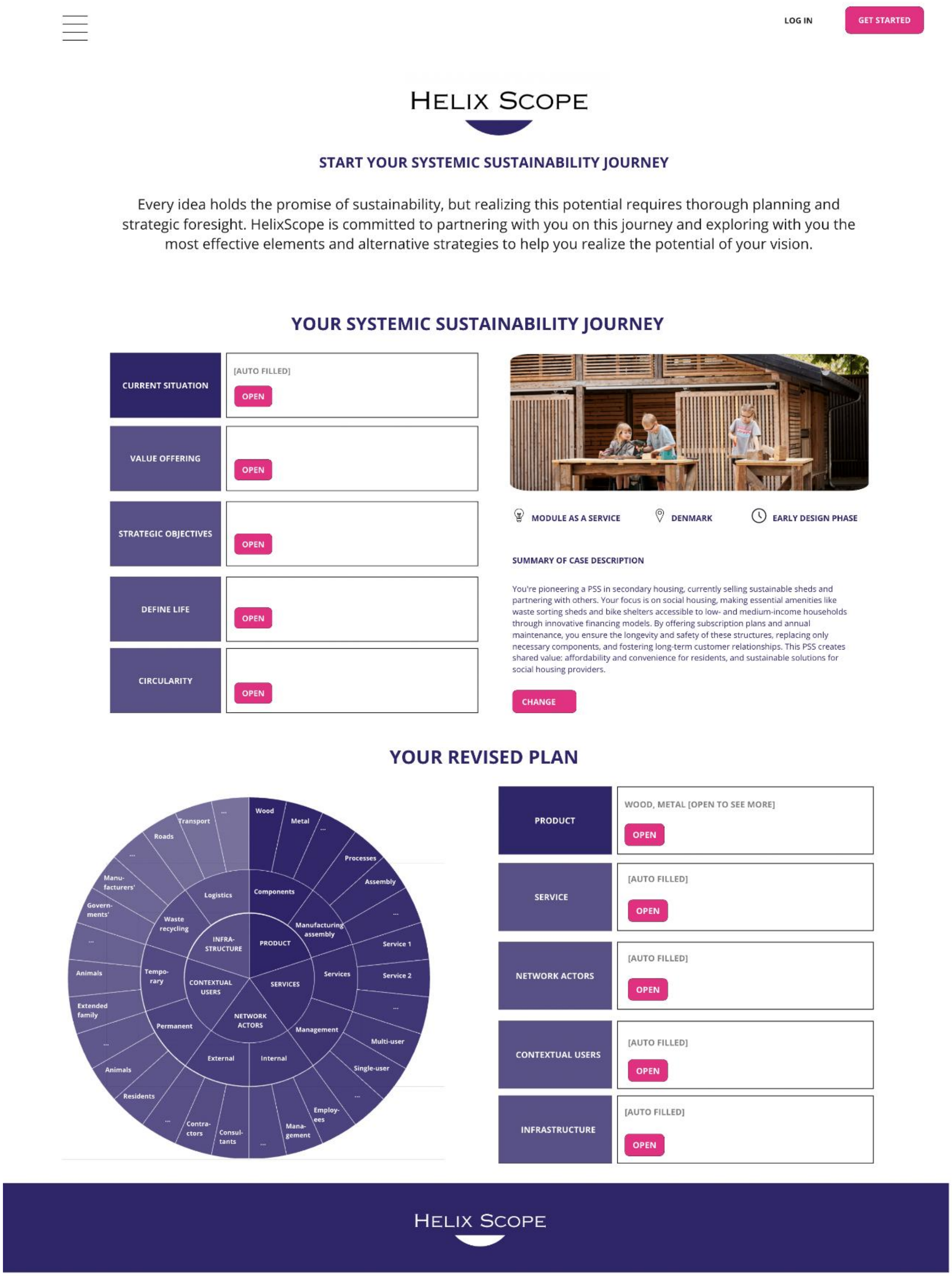

Figure 27: Revised business proposal in Helix Scope. Source: Author