**Master Thesis**

Sophie Denneboom

# *Structuring for Sustainability*

## *Exploring Stakeholder Dynamics, Revenue Models, and Barriers in Product-Service Systems for the Infrastructure Sector*

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# Structuring for Sustainability: Exploring Stakeholder Dynamics, Revenue Models, and Barriers in Product-Service Systems for the Infrastructure Sector


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# Preface

The past six months have revolved almost entirely around Product-Service Systems, something you will become very familiar with as you read on (if you are not already). When I was 18, just starting my bachelor's in technology, Policy and Management at TU Delft, I had no idea where the road would lead. Now, five years later, I find myself wrapping up my master in Construction Management and Engineering. During my bachelor, I developed a deep interest in infrastructure, which ultimately inspired me to pursue this master's. I wanted to gain a more comprehensive understanding of how infrastructure is managed and how it can be improved.

Throughout my master's, one topic kept coming up, sustainability. It is something nearly every student seems to care about, and I am no exception. While the Netherlands is making great strides in sustainable infrastructure, as I saw firsthand during a study trip to Thailand, where the contrast was striking, there is still a lot of room to grow. I knew I wanted my thesis to contribute, in some small way, to that effort. I have also always been interested in construction contracts, which led me to approach Leon after his course on the topic. Leon was immediately enthusiastic and encouraged me to speak with Daan to further explore my interests. That conversation introduced me to: "De Circulaire Weg" (The Circular Road program), and soon after, I connected with Kaleem. Just like that, I had a research topic, a committee, and was ready to start, after a well-deserved vacation to Thailand, of course.

Now, after months of research (and many hours behind my desk), I believe I have achieved the goal I set at the beginning: to contribute meaningfully to sustainability in the infrastructure industry. My thesis is based on real-world projects that offer valuable lessons and can serve as examples for others interested in similar approaches, or for the people involved in these very projects to reflect and learn. Writing this thesis has not always been easy, but I have been fortunate to learn a lot and to have the support of many incredible people along the way.

First and foremost, I would like to thank my committee: Daan Schraven, Leon Hombergen, and Kaleem Ullah. Your guidance has been invaluable. Daan, thank you for introducing me to the people behind The Circular Road and for your useful input. Leon, thank you for pushing me to think critically and offering new perspectives. And Kaleem, thank you for your patience, your many helpful comments, and for answering my endless questions.

I would also like to thank my company supervisor, Philine Goldbohm from dutch process innovators (DPI), for supporting me and providing practical insights throughout the process. A big thanks as well to all my colleagues at DPI for their positivity and interest in my work. And, of course, I am grateful to everyone involved in The Circular Road program who participated in interviews, shared their experiences, and who continue to work toward real, impactful change in the infrastructure sector. Your dedication is truly inspiring.

Finally, to all the people in my personal life. Coco, my girlfriend, thank you for your unwavering support, for putting up with my thesis-induced stress, and for always believing in me. To my parents, thank you for giving me the space and support to study without worry. To my brother, Levi, for reviewing the entire report. And to my friends: thank you for listening to me talk about PSS far more than you probably wanted to, for cheering me on, and simply being there. Thanks to all of you, I was able to complete this thesis.

**Enjoy reading!**

*Sophie Denneboom*
*Delft, June 2025*

## Executive Summary


The construction industry in the Netherlands is under increasing pressure to transition toward more sustainable practices, as it is responsible for 40% of national $CO_2$ emissions (Rijksdienst voor Ondernemend Nederland, 2024), nearly 50% of total material consumption, and 36% of all waste generation (Circle Economy & Metabolic, 2022; Ministerie van Infrastructuur en Waterstaat et al., 2022). However, various barriers continue to hinder this transition, including high upfront costs, limited adoption of new technologies, a general resistance to change, and conventional contracting structures that offer little incentive for sustainability or innovation (Ayarkwa et al., 2022; Cramer, 2023; Geng et al., 2023; Nyström et al., 2016; Stam et al., 2023). In response, Product-Service Systems (PSS) have emerged as a potential strategy for aligning financial and environmental objectives by shifting the focus from asset ownership to service delivery (Baines et al., 2007). PSS offers a framework that redistributes risk, fosters stakeholder collaboration, reduce waste, and encourages long-term value creation (Teigiserova et al., 2023; Teigiserova & Schraven, 2024). Nevertheless, implementation in infrastructure remains limited and complex due to unclear stakeholder dynamics, project scale, and fragmented responsibilities. In particular, little is known about how revenue models, such as input-based, availability-based, usage-based, and performance-based mechanisms (Van Ostaeyen et al., 2013), can be effectively structured to incentivize sustainable and innovative outcomes in real-world construction settings. This research investigates how PSS-based contracts can be leveraged to drive sustainability in the construction industry, with a particular focus on the role of revenue models. It aims to understand how financial and operational mechanisms within PSS influence innovation, reduce environmental impact, and help overcome persistent barriers to sustainable practices. To achieve this, it analyses eight pilot projects from The Circular Road program, examines stakeholder dynamics, identifies key implementation barriers, and explores whether payment structures can stimulate sustainable innovation. This leads to the central research question:

*“How can different revenue models within Product-Service Systems be structured to stimulate sustainability in the construction industry?”*

To investigate how revenue models within PSS can stimulate sustainability in the construction industry, this research employed a multi-method qualitative approach. First, a two-phase literature review was conducted to establish a theoretical foundation on PSS, revenue models, and implementation barriers in the construction sector, and to contextualise the empirical findings. Second, a multiple case study analysis was carried out using eight pilot projects from The Circular Road program, which offered real-world insights into how PSS is being implemented in infrastructure. These cases included both ongoing and completed projects and were analysed using the Functional Hierarchy Model (FHM) of Van Ostaeyen et al. (2013) to assess project structure, stakeholder interaction, and theoretical revenue model alignment. Third, semi-structured interviews were conducted with nineteen stakeholders, including public clients, contractors, and consultants, to explore their experiences with PSS, focusing on project collaboration, financial mechanisms, and sustainability integration. Finally, a workshop was held with participants from the Noorderkroon project to validate findings, assess group dynamics, and observe how co-creation unfolds in practice.

The findings reveal that collaboration between clients and contractors in PSS contracts is largely shaped by the degree of early co-creation and the level of design freedom granted to the contractor. Projects where contractors were involved earlier and allowed more functional input typically integrated a higher proportion of sustainability measures. While all analysed projects featured sustainable components, those with greater contractor autonomy, typically aligned with more performance-oriented structures in theory, demonstrated deeper sustainability integration. However, a notable misalignment was observed between theoretical revenue models proposed using the FHM and those applied in practice. In most cases, traditional input- or availability-based mechanisms were used, even where other models

might have been better suited. Additionally, the research showed that stakeholders did not consider the revenue model itself to be the key driver of sustainability. Instead, a collaborative mindset, open dialogue, and trust were seen as more influential factors. Finally, the study identified a wide range of barriers to implementing PSS in infrastructure, including financial obstacles such as high upfront costs, pricing uncertainties, and residual value disputes, as well as organisational, behavioural, regulatory, and contextual challenges. While some of these barriers aligned with those in broader PSS literature on construction, many were unique to the infrastructure context, highlighting the complexity and novelty of applying PSS in this sector.

The findings of this research highlight the complexity of implementing PSS in infrastructure. While the theoretical promise of PSS includes improved sustainability, efficiency, and innovation, real-world application is shaped by stakeholder dynamics, project-specific constraints, and practical limitations in contract design. Notably, sustainability outcomes were not directly linked to specific revenue models but were instead influenced by the degree of design freedom granted to contractors and the openness of collaboration between parties. Furthermore, although the FHM was found to be a useful analytical tool, it proved too complex for direct application in practice without adjustments. A wide range of barriers also emerged, many of which had not been identified in existing literature, particularly those tied to contextual and infrastructure-specific challenges. Based on these insights, the research recommends adapting theoretical tools like the FHM to suit practical needs, encouraging early co-creation to foster innovation, and further investigating how PSS implementation can be scaled in more diverse construction settings. These steps will be vital for aligning financial mechanisms with sustainability goals and overcoming the persistent barriers to adoption.

This research contributes to a deeper understanding of how PSS-based contracts can support the sustainability transition in the construction sector by aligning service delivery with innovative financial structures and collaborative stakeholder dynamics. By analysing eight pilot projects from The Circular Road program, this study sheds light on the interaction between revenue models, sustainability integration, and practical implementation challenges. The insights generated offer both theoretical contributions and actionable recommendations for practitioners seeking to implement PSS in infrastructure. As the industry continues to search for scalable, circular, and climate-resilient solutions, this research underscores the importance of context-sensitive design, early collaboration, and flexible contract models to unlock the full potential of Product-Service Systems.

## Samenvatting

De bouwsector in Nederland staat onder toenemende druk om over te stappen op duurzamere praktijken, aangezien deze sector verantwoordelijk is voor 40% van de nationale $CO_2$-uitstoot (Rijksdienst voor Ondernemend Nederland, 2024), bijna 50% van het totale materiaalverbruik en 36% van alle afvalproductie (Circle Economy & Metabolic, 2022; Ministerie van Infrastructuur en Waterstaat et al., 2022). Deze overgang wordt echter nog steeds belemmerd door verschillende barrières, zoals hoge aanloopkosten, beperkte toepassing van nieuwe technologieën, een algemene weerstand tegen verandering en conventionele contractstructuren die weinig stimulans bieden voor duurzaamheid of innovatie. (Ayarkwa et al., 2022; Cramer, 2023; Geng et al., 2023; Nyström et al., 2016; Stam et al., 2023). Als reactie hierop zijn Product-Service Systemen (PSS) naar voren gekomen als een potentiële strategie om financiële en duurzaamheidsdoelstellingen op elkaar af te stemmen door de focus te verleggen van eigendom naar dienstverlening (Baines et al., 2007). PSS biedt een raamwerk waarin risico's worden herverdeeld, samenwerking tussen belanghebbenden wordt bevorderd, afval wordt verminderd en waardecreatie op de lange termijn wordt gestimuleerd (Teigiserova et al., 2023; Teigiserova & Schraven, 2024). Toch blijft de implementatie binnen infrastructuur beperkt en complex vanwege onduidelijke stakeholderdynamiek, schaalgrootte van projecten en gefragmenteerde verantwoordelijkheden. In het bijzonder is er weinig bekend over hoe verdienmodellen, zoals input-gebaseerde, beschikbaarheid gebaseerde, gebruik gebaseerde en prestatie gebaseerde mechanismen (Van Ostaeyen et al., 2013), effectief kunnen worden gestructureerd om duurzame en innovatieve uitkomsten in de praktijk te stimuleren. Dit onderzoek geeft inzicht in hoe PSS-gebaseerde contracten kunnen worden ingezet om duurzaamheid in de bouwsector te bevorderen, met bijzondere aandacht voor de rol van verdienmodellen. Het doel is te begrijpen hoe financiële en operationele mechanismen binnen PSS innovatie beïnvloeden, de impact op het milieu verminderen en bijdragen aan het overwinnen van hardnekkige belemmeringen voor duurzame praktijken. Om dit te bereiken, zijn acht pilotprojecten uit het programma De Circulaire Weg geanalyseerd, is de stakeholderdynamiek onderzocht, zijn belangrijke implementatiebarrières geïdentificeerd en is bekeken of betalingsstructuren duurzame innovatie kunnen stimuleren. Dit leidt tot de centrale onderzoeksvraag:

*“Hoe kunnen verschillende verdienmodellen binnen Product-Service Systemen worden gestructureerd om duurzaamheid in de bouwsector te stimuleren?”*

Om te onderzoeken hoe verdienmodellen binnen PSS duurzaamheid in de bouwsector kunnen stimuleren, is gebruik gemaakt van een multi-methodische kwalitatieve aanpak. Eerst werd een literatuurstudie in twee fasen uitgevoerd om een theoretische basis te leggen over PSS, verdienmodellen en implementatiebarrières in de bouwsector, en om de empirische bevindingen te contextualiseren. Vervolgens werd een meervoudige casestudie uitgevoerd aan de hand van acht pilotprojecten uit het programma De Circulaire Weg, die praktische inzichten boden in hoe PSS in infrastructuurprojecten wordt toegepast. Deze casussen, bestaande uit lopende en afgeronde projecten, werden geanalyseerd met behulp van het Functioneel Hiërarchisch Model (FHM) van Van Ostaeyen et al. (2013) om projectstructuren, interactie tussen stakeholders en theoretische verdienmodellen te evalueren. Vervolgens zijn 19 semigestructureerde interviews afgenomen met stakeholders, waaronder publieke opdrachtgevers, aannemers en adviseurs, om hun ervaringen met PSS te verkennen met betrekking tot samenwerking, financiële structuren en duurzaamheid. Tot slot werd een workshop georganiseerd met deelnemers uit het Noorderkroon-project om de bevindingen te valideren, groepsdynamiek te observeren en co-creatie in de praktijk te onderzoeken.

Uit de resultaten blijkt dat samenwerking tussen opdrachtgever en opdrachtnemer in PSS-contracten grotendeels wordt bepaald door de mate van vroege co-creatie en de ontwerpvrijheid die aan de opdrachtnemer wordt verleend. Projecten waarin opdrachtnemers eerder betrokken waren en

functionele input konden leveren, integreerden doorgaans meer duurzame maatregelen. Hoewel alle geanalyseerde projecten duurzame elementen bevatten, toonden projecten met meer autonomie voor de opdrachtnemer, vaak theoretisch afgestemd op prestatiegerichte structuren, een diepere integratie van duurzaamheid. Tegelijkertijd werd een duidelijke mismatch geconstateerd tussen de theoretisch voorgestelde verdienmodellen volgens het FHM en de modellen die in de praktijk werden toegepast. In de meeste gevallen werd teruggegrepen op traditionele input- of beschikbaarheidsmodellen, ook wanneer andere modellen beter geschikt leken. Bovendien gaven stakeholders aan dat het verdienmodel op zichzelf niet als bepalende factor voor duurzaamheid werd gezien. In plaats daarvan werden een samenwerkingsgerichte mentaliteit, open communicatie en wederzijds vertrouwen genoemd als de belangrijkste drijfveren. Tot slot bracht het onderzoek een breed scala aan belemmeringen aan het licht voor de implementatie van PSS in infrastructuur, waaronder financiële obstakels zoals hoge aanvangskosten, prijsbepaling en discussies over restwaarde, evenals organisatorische, gedragsmatige, regelgevende en contextuele uitdagingen. Sommige van deze belemmeringen overlappen met bestaande literatuur over PSS in de bouwsector, maar veel zijn specifiek voor de infrastructuurcontext, wat wijst op de complexiteit en het vernieuwende karakter van PSS in deze sector.

De bevindingen van dit onderzoek benadrukken de complexiteit van het implementeren van PSS in infrastructuur. Hoewel PSS theoretisch bijdraagt aan duurzaamheid, efficiëntie en innovatie, blijkt de toepassing in de praktijk sterk beïnvloed te worden door stakeholderrelaties, project specifieke beperkingen en contractuele obstakels. Opvallend was dat duurzaamheid niet direct samenhing met specifieke verdienmodellen, maar eerder met de ontwerpvrijheid van de opdrachtnemer en de mate van samenwerking. Daarnaast bleek het FHM weliswaar nuttig als analytisch instrument, maar te complex voor directe toepassing in de praktijk zonder aanpassingen. Er kwamen ook diverse nieuwe belemmeringen naar voren, met name contextuele en infrastructuur specifieke, die nog niet eerder in de literatuur waren beschreven. Op basis van deze inzichten beveelt dit onderzoek aan om theoretische instrumenten zoals het FHM aan te passen aan praktische behoeften, vroege co-creatie te stimuleren en verder onderzoek te doen naar schaalbare PSS-toepassingen in verschillende bouwcontexten. Deze stappen zijn cruciaal om financiële prikkels beter af te stemmen op duurzaamheidsdoelen en om de structurele belemmeringen voor bredere toepassing te overwinnen.

Dit onderzoek draagt bij aan een beter begrip van hoe PSS-gebaseerde contracten de transitie naar duurzaamheid in de bouwsector kunnen ondersteunen door dienstlevering te koppelen aan innovatieve financiële structuren en samenwerking tussen stakeholders. Door acht pilotprojecten van De Circulaire Weg te analyseren, biedt deze studie inzichten in de relatie tussen verdienmodellen, integratie van duurzaamheid en praktische implementatie-uitdagingen. De gegenereerde inzichten leveren zowel theoretische bijdragen als bruikbare aanbevelingen voor professionals die PSS willen toepassen binnen infrastructuurprojecten. Nu de sector op zoek is naar schaalbare, circulaire en klimaatbestendige oplossingen, benadrukt dit onderzoek het belang van contextgevoelig ontwerp, vroege samenwerking en flexibele contractmodellen om het volledige potentieel van Product-Service Systemen te benutten.

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## List of Abbreviations

| Abbreviation | Definition |
|---|---|
| AAS | As a Service |
| PSS | Product-Service Systems |
| RWS | Rijkswaterstaat |
| FHM | Functional Hierarchy Model |
| IB | Input-Based |
| AB | Availability-Based |
| UB | Usage-Based |
| PB | Performance-Based |
| IAAS | Infrastructure as a Service |
| MKI | Environmental Cost Indicator |
| DBFM | Design, Build, Finance, and Maintain |

# Chapter One: Introduction

In the Netherlands, the built environment is responsible for 40% of all $CO_2$ emissions, making the sustainability transition a crucial topic for the construction sector (Rijksdienst voor Ondernemend Nederland, 2024). The sector is also the most material-intensive in the country, responsible for nearly 50% of total material consumption, while only 8% of the materials used in the Dutch built environment are sourced from secondary or recycled inputs (Circle Economy & Metabolic, 2022). Moreover, construction and demolition activities generate nearly 36% of all waste, making the sector the largest contributor to national waste streams (Ministerie van Infrastructuur en Waterstaat et al., 2022). However, several obstacles hinder the construction industry's shift toward green construction practices. These barriers include a slow adoption rate for innovative technologies, limited shared understanding of sustainability issues, the higher cost of green materials and processes, and a general resistance to change within the industry (Ayarkwa et al., 2022; Cramer, 2023; Geng et al., 2023; Stam et al., 2023). Traditional contracting structures also play a significant role in limiting innovation and sustainability efforts (Bullen & Davis, n.d.; Ershadi et al., 2021). While Design-Build contracts offer contractors some creative freedom, they also transfer most of the risks to the contractor, potentially discouraging innovative approaches (Nyström et al., 2016). In contrast, Design-Bid-Build contracts place risk on the principal, as they provide the design upfront, but this limits opportunities for the contractor to innovate (Nyström et al., 2016).

Product-Service Systems (PSS) present a promising model to address these challenges. By integrating products and services, PSS shifts the focus from product ownership to usage, redistributing risks and responsibilities while encouraging innovative, sustainable practices (Baines et al., 2007). PSS has the potential to bridge technical and social gaps by fostering stakeholder collaboration, enhancing knowledge sharing, securing funding, and reducing waste (Teigiserova et al., 2023). In the context of public infrastructure procurement, PSS offers opportunities to integrate circularity and sustainability into projects, making it an effective tool for the construction sector's green transition (Teigiserova et al., 2023; Teigiserova & Schraven, 2024).

A key implementation of PSS is through As a Service (AAS) contracts*,* which provide a service instead of a product to the costumer (Baines et al., 2007; De Circulaire Weg, 2022b). In an AAS contract, customers pay for the use of an asset, and the responsibility for maintaining and optimising the asset lies with the provider. This model promotes long-term sustainability by aligning with circular economy principles, as the service provider has a personal interest in ensuring the asset's performance and longevity (Baines et al., 2007). According to Geissdoerfer et al. (2017) sustainability refers to "the balanced and systemic integration of intra- and intergenerational economic, social and environmental performance" (p. 759). While circular economy is defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer et al., 2017, p. 759).

However, there is a significant knowledge gap regarding how revenue models within such contracts can be structured to stimulate sustainability. Specifically, it remains unclear which forms of payment structures, such as input-based, availability-based, usage-based or performance-based mechanisms (Van Ostaeyen et al., 2013), would incentivize contractors to innovate while addressing sustainability challenges in the construction industry.

Further complicating the issue is the need to balance economic feasibility with environmental goals. Contractors frequently encounter significant challenges when implementing sustainable practices, such as the high upfront expenses of acquiring sustainable materials and the fact that financial institutions and investors continue to prioritise cost (Hayles & Kooloos, 2008; Safinia et al., 2017). An additional factor contributing to the hesitancy to engage in sustainable building is the concern of possible delays or project abandonment (Maqbool & Amaechi, 2022; Richardson & Lynes, 2007). These factors limit contractors' ability to invest in sustainability. Innovative revenue models could help to overcome these obstacles by realigning financial incentives to reward sustainable achievements. Nevertheless, this area remains underexplored, particularly in the construction sector, where the complexity of projects and diversity of stakeholders pose unique challenges to implementing such systems.

## 1.1 Problem Statement

Growing environmental concerns and regulatory pressure are making the construction industry more aware of the need for sustainable methods. However, a number of barriers still make it challenging to incorporate sustainability into construction projects, such as high upfront costs, a lack of technological adoption, resistance to change, and traditional contracting structures that don't provide incentives for sustainability and innovation (Cramer, 2023; Hayles & Kooloos, 2008; Nyström et al., 2016; Stam et al., 2023). By sharing risks and responsibilities, aligning incentives for long-term sustainability, and moving the emphasis from ownership to usage, PSS presents a possible alternative (Baines et al., 2007). However, implementing PSS in infrastructure remains challenging due to the sector's complexity, project scale, and the involvement of multiple stakeholders with differing interests and expectations (Teigiserova & Schraven, 2024). The dynamics between clients and contractors play a crucial role in shaping how effectively these models are applied in practice, yet these interactions are not well understood. Furthermore, various financial, organisational, behavioural, and regulatory barriers continue to limit the adoption of PSS models.



Furthermore, it is unclear how payment mechanisms in these contracts may successfully promote sustainable construction practices while also addressing financial barriers. The challenge lies in aligning payment structures, such as input-based, availability-based, usage-based, or performance-based models (Van Ostaeyen et al., 2013), with the contractors' needs, in a way that encourages sustainable practices while addressing the industry's financial and operational challenges. Beyond payment structures, there is limited understanding of how sustainability measures are embedded across different levels of project design and execution, and how this is influenced by the degree of freedom contractors are given within the PSS framework.

Therefore, further research is needed to explore not only how revenue models can support both financial and sustainability objectives, but also how stakeholder dynamics and existing barriers influence the effective implementation of PSS in infrastructure. This leads to the following problem statement:

*The implementation of PSS to support sustainability goals in infrastructure has not been fully explored. Additionally, the potential of revenue models within Product-Service Systems to incentivise sustainable practices in construction remains largely underexplored. While PSS offer a promising approach to aligning financial and operational strategies with sustainability goals, the industry lacks a comprehensive understanding of how stakeholder interactions and existing barriers impact the practical application of PSS, and how these dynamics influence the integration of sustainability measures throughout infrastructure projects.*

### 1.1.1 Research Gap

The construction industry is undergoing a critical transition toward more sustainable and circular practices. However, despite a clear willingness to adopt sustainable methods, many businesses face significant challenges in this process. These challenges often stem from uncertainty about how to navigate the complexities of implementing sustainability measures effectively and high upfront investments (Hayles & Kooloos, 2008; Safinia et al., 2017). Public procurement has emerged as a key driver in advancing sustainability within the construction sector, serving as a powerful tool to encourage environmentally responsible practices across projects (Lingegård et al., 2021).

PSS have been identified as a particularly promising approach to integrate sustainability into public infrastructure procurement (Teigiserova & Schraven, 2024). While PSS are widely used in other industries, they are a relatively new and underutilised model in the construction industry (Schraven et al., 2022). Research has shown that PSS have the potential to increase sustainability and circularity practices in the construction industry (Teigiserova et al., 2023). However, it is unclear which specific characteristics of these systems, such as different revenue models, are most helpful in achieving these results. Furthermore, a number of barriers to implementing PSS in practice have been identified, the ability of revenue models to address or mitigate these barriers has not been adequately studied.

Therefore, the problem addressed in this research is the lack of clarity and understanding regarding how PSS can be effectively implemented to support sustainability goals in the infrastructure sector. In particular it remains unclear how stakeholder dynamics shape the practical application of PSS, how different revenue models can be structured to incentivise sustainable practices, and which barriers are hindering the successful implementation of PSS in construction projects. This research aims to bridge these gaps by examining how revenue models in PSS can be structured to promote sustainability and innovation, exploring how stakeholder interactions influence PSS implementation, and identifying how various revenue models may help overcome barriers that currently hinder the wider adoption of PSS in infrastructure projects.

### 1.1.2 Research Goal and Objective

This research will investigate PSS-based contracts and explore how revenue models within PSS can be designed to drive sustainability in the construction industry. This means understanding the financial and operational mechanisms of these contracts and the best payment structures to encourage innovation, reduce environmental impact and overcome the barriers to sustainability. By looking at both the theory and practice of revenue models this research aims to contribute to the broader goal of accelerating the sustainability transition in the built environment.



The purpose of the research is to offer theoretic insights and practical recommendations for structuring revenue models in PSS in a way that balances financial incentives with sustainability goals. To accomplish this, the study will identify and analyse the barriers that contractors experience when implementing sustainable practices under such contracts. It will examine the revenue models used in eight projects from The Circular Road and assess how they affect sustainability. Additionally, it will explore payment structures such as input-based, availability-based, usage-based or performance-based to see if they can stimulate sustainable innovation in the construction industry.

## 1.2 Research Questions

To fulfil the research objective, the following research question will be addressed:

*How can different revenue models within Product-Service Systems be structured to stimulate sustainability in the construction industry?*

In addition to the main research question, three sub-questions have been formulated. These supporting questions are intended to explore different dimensions of PSS models in the construction industry and address critical aspects of their implementation. The first sub-question aims to analyse how the client and contractor interact within a PSS:

1. *How do the client and contractor collaborate within a Product-Service System to align service delivery with sustainability goals throughout the project lifecycle?*

In the second sub-question, the effectiveness of demand-driven, effect-driven, or solution-driven payment strategies in promoting innovation and sustainability is examined:

2. *How do different payment mechanisms relate to the implementation of sustainable and innovative solutions in Product-Service Systems?*

The third sub-question investigates the barriers encountered in implementing PSS, providing insights into the challenges experienced by stakeholders:

3. *What are the barriers to implementing the Product-Service System in the infrastructure sector?*

## 1.3 Research Relevance

The intention of this research is to address the problem that is experienced in practice and close the gap in the literature about the impact of various revenue models in a PSS and how they affect sustainability. This research is based on the goal of contributing to the larger issue of sustainability in the construction industry.

### 1.3.1 Scientific Relevance



Despite being relatively new in the construction industry, PSS have been widely studied and applied to other industries. For example, Signify applies Light-as-a-Service to deliver lighting solutions in a circular and sustainable way (Brummelhuis & Marinelli, 2021; De Circulaire Weg, 2022b). Furthermore, Schraven et al. (2022) conducted extensive research into the effectiveness of infrastructure AAS in terms of circularity. However, while the positive impact of PSS on circularity and on the other aspects of sustainability is well acknowledged, there is still a lot that needs to be understood about the mechanisms that enable these outcomes. Specifically, how financial structures and revenues contribute to achieving these effects has not been studied in-depth. By focusing on the financial dimension of PSS, this research aims to provide insights into how revenue models can stimulate sustainable practices in the construction industry. This contribution is particularly relevant because it supports and builds on the work of Schraven et al. (2022), providing a more detailed context for circular economy-based business models and adoption motivations. As a result, this study fills gaps in the existing literature on circular economy practices in construction, as well as the larger construction sector, and contributes to the scientific discussion on financial motivation, sustainability, and new types of contracts.

### 1.3.2 Societal Relevance

Of all $CO_2$ emissions in the Netherlands, 40% come from construction, which also produces twenty-five million tonnes of waste yearly from both new construction and the destruction of existing buildings (Rijksdienst voor Ondernemend Nederland, 2024; Rijkswaterstaat, 2015). The fact that only 38% of these materials are recycled is cause for concern since it indicates a significant inefficiency in the utilisation of resources (Centraal Bureau voor de Statistiek, 2019). Due to its scope and impact, the construction sector plays a critical role in reaching the United Nations 17 Sustainable Development Goals (SDGs), which must be accomplished by 2030 (Fei et al., 2021). PSS have surfaced as a potential solution for these problems, promoting circularity, resource efficiency, and long-term sustainability (Baines et al., 2007; Schraven et al., 2022). However, more information is needed about how much PSS revenue models could encourage these sustainable behaviours, especially in the building industry. Through an analysis of how financial incentives could facilitate the adoption of more environmentally friendly methods in urban development and infrastructure, this research seeks to close that gap. The research's focus on revenue models aids in addressing the urgent social need to lessen the building industry's environmental impact while encouraging business model innovation. Eventually, the insights gathered will help to achieve national and global sustainability goals by linking economic incentives with environmental standards.

### 1.3.3 Practical Relevance

The construction industry is transitioning from a traditional linear economic model, in which materials and components are simply discarded as waste, to a circular economic model, in which materials are reused and repurposed to reduce waste and environmental impact (Benachio et al., 2020). However, there are several financial obstacles to this shift, including the high initial costs of sustainable materials and the fact that the primary concern is costs (Hayles & Kooloos, 2008). This research has practical relevance because it demonstrates how these barriers can be removed by restructuring financial incentives, lowering stakeholder risk, and using creative revenue models through a PSS. Additionally, by using actual cases from The Circular Road, this research grounds its conclusions in actual, hands-on experiences and tangible examples of the way these models are used and the outcomes they achieve. These case studies shed light on the financial, operational, and environmental advantages of PSS, while also emphasising important problems and potential for progress.

# Chapter Two: Theoretical framework

To effectively implement PSS in the infrastructure sector, a clear understanding of the underlying business models, supporting revenue mechanisms, and potential implementation barriers is essential. This chapter provides the theoretical foundation for this research by exploring how PSS can drive sustainability in construction, how revenue models can incentivise sustainable outcomes, and what challenges may hinder adoption.

Section 2.1 introduces the concept of PSS and its application in various industries, with a particular focus on how it can create value and promote sustainability in the construction sector. Section 2.2 builds on this by explaining the role of revenue models in PSS and how different models can shape incentives for both clients and contractors. Section 2.3 examines the key barriers from the literature that limit the successful implementation of PSS in infrastructure projects, spanning financial, organisational, behavioural, and regulatory dimensions.

## 2.1 Product-Service Systems

A PSS is a business model that integrates products and services to meet customer needs in an innovative way, shifting the focus from product ownership to the delivery of functional value (Moro et al., 2022; Scheepens et al., 2016). Instead of emphasising the sale and ownership of individual products, PSS prioritizes the continuous delivery of service-based value embedded within those products (França et al., 2017). This approach has been proposed as a way to promote sustainability and support the deliberate development of business models (Tukker, 2004), while offering an effective solution for delivering value to customers (Reim et al., 2015). Figure 1, from Tukker (2004), categorizes different types of PSS, illustrating the transition from product-oriented to result-oriented models with increasing service content.

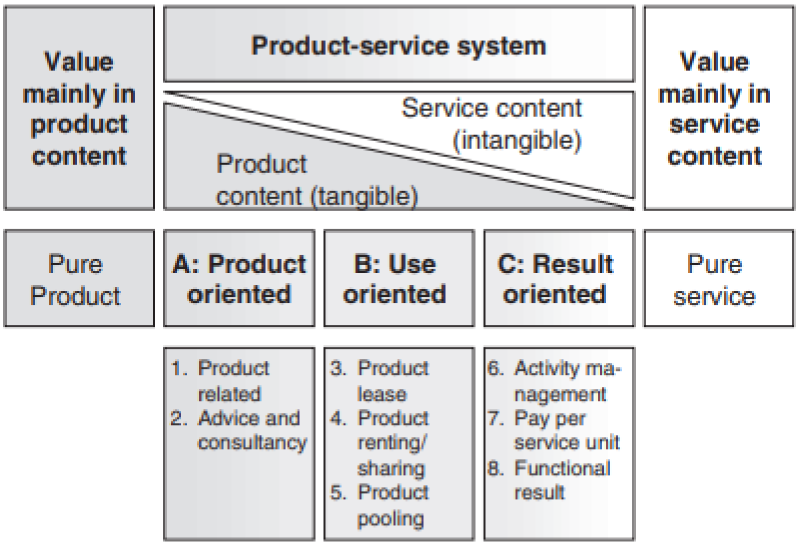


*Figure 1: Main and subcategories of PSS (Tukker, 2004)*

Businesses adopt PSS models to boost profitability, differentiate themselves in the market, and become more competitive (Annarelli et al., 2016). PSS offers opportunities for increased profit margins by adding service value to products while reducing lifecycle costs (Annarelli et al., 2016). By integrating services with products, businesses can establish long-term customer relationships, secure recurring revenue, and minimize environmental impact (Reim et al., 2015). Evans et al. (2017) highlight that PSS allows companies to internalize externalities such as maintenance and repairs, shifting responsibility from the customer to the provider. This not only improves service efficiency but also fosters innovation in sustainable business models by extending product lifespans and optimizing resource use (Scheepens et al., 2016). PSS is particularly relevant in contexts where traditional sales models are inefficient, where businesses aim to improve sustainability, or where customers prioritize access over ownership (Scheepens et al., 2016).

PSS models are widely applied across various sectors, including mobility, manufacturing, and consumer goods. In the mobility industry, companies like Swapfiets provide bicycles as a service, where customers pay a monthly fee for a fully maintained and replaceable bike (van Tiel, 2019). Similarly, in manufacturing, businesses lease industrial equipment instead of selling it outright, ensuring long-term functionality through continuous servicing (Mahut et al., 2017). The consumer goods sector has also embraced PSS, with companies offering pay-per-use appliances, such as washing machines, reducing the need for ownership while ensuring regular maintenance and upgrades (Beuren et al., 2013). In material handling, Toyota Industries provides forklift rentals, allowing customers to pay for usage while Toyota manages maintenance, upgrades, and disposal, offering a seamless operational solution (Brambila-Macias et al., 2018). These examples are summarised in Table 1.

*Table 1: Examples of PSS across different industries*

| Industry | Example | Description |
|---|---|---|
| **Mobility** | Swapfiets (van Tiel, 2019) | Bicycle-as-a-service model where customers pay a monthly fee for a fully maintained and replaceable bike. |
| **Manufacturing** | Industrial equipment leasing (Mahut et al., 2017) | Businesses lease industrial equipment instead of buying it, ensuring long-term functionality through continuous servicing. |
| **Consumer Goods** | Pay-per-use appliances (Beuren et al., 2013) | Companies offer washing machines and other appliances on a pay-per-use basis, reducing the need for ownership while providing maintenance and upgrades. |
| **Material Handling** | Toyota Industries (Brambila-Macias et al., 2018) | Forklift rental service where customers pay based on usage while Toyota manages maintenance, upgrades, and disposal. |



### 2.1.1 PSS in the Construction Industry

While PSS is widely used in other industries, its application in the construction sector presents unique opportunities and challenges. Given the high costs and resource-intensive nature of construction projects (Hayles & Kooloos, 2008), PSS can play a crucial role in reducing material waste, optimising equipment use, and promoting sustainable business models. Construction companies increasingly rely on equipment-as-a-service models, where machinery such as autonomous electric haulers, electric excavators, and electric crushers is rented rather than purchased, this reduces costs and shifts the maintenance and operations risks to the provider (Ruvald et al., 2019) Additionally, lighting-as-a-service solutions, such as those offered by Signify, allow building owners to pay for lighting performance rather than purchasing fixtures, reducing energy consumption and maintenance costs (Brummelhuis & Marinelli, 2021).

This shift toward service-based models not only provides economic benefits but also contributes significantly to enhancing sustainability in the construction industry. PSS promotes circular practices and encourages life cycle thinking (Teigiserova & Schraven, 2024). PSS offers co-creation opportunities between clients and producers (Boukhris et al., 2017). Research shows that when clients are actively involved in contract formulation and intentionally push for circular outcomes, infrastructure projects tend to achieve higher levels of material circularity (Teigiserova et al., 2023). This collaboration between the client and the provider fosters knowledge exchange, which is essential for reducing uncertainty and integrating sustainable practices throughout a project's life cycle (Teigiserova et al., 2023). By moving away from traditional ownership models to service-based contracts, such as equipment-as-a-service or lighting-as-a-service, PSS enables more efficient resource use and minimizes waste (Teigiserova & Schraven, 2024). Moreover, public procurement is increasingly focused on paying for delivered performance instead of physical units, encouraging providers to design durable, efficient, and easily maintainable systems (Teigiserova & Schraven, 2024). In doing so, PSS supports the broader transition toward a more circular and sustainable construction industry.

## 2.2 Revenue Models

A revenue mechanism defines the way a company generates income from its products or services (Van Ostaeyen et al., 2013). As manufacturers transition from traditional product-based approaches to PSS, they must reconsider their pricing strategies and revenue models to align with service-oriented business structures (Kowalkowski et al., 2015; Saccani et al., 2024). Revenue models play a crucial role in shaping incentives and customer behaviour, influencing not only profitability for PSS providers but also the cost-benefit balance for clients (Saccani et al., 2024).

For clients, PSS models offer distinct added value compared to traditional procurement. Instead of purchasing and managing an asset themselves, clients receive an integrated and customised service that fulfils their functional needs (Kowalkowski et al., 2015; Tukker, 2004). This allows clients to focus on their core activities, while the service provider takes responsibility for the asset's performance and maintenance over its lifecycle (Tukker, 2004). The nature of PSS also fosters long-term relationships between client and provider, built on trust and ongoing collaboration (Kowalkowski et al., 2015; Tukker, 2004).



Moreover, because PSS integrates both the delivery of an asset and its ongoing service, it incentivises providers to design and implement robust, high-quality, and sustainable solutions (Apostolov et al., 2018; Tukker, 2004). When the provider remains responsible for performance and lifecycle costs, they have a vested interest in using durable materials, ensuring maintainability, and minimising failures, all of which directly benefit the client through reduced downtime, better asset performance, and lower long-term operational costs.

When revenue structures are aligned with sustainability factors, such as resource efficiency, extended product lifespans, and $CO_2$ reduction, they contribute to positive environmental outcomes (Kjaer et al., 2019). This alignment supports both public and private sector sustainability goals, offering clients not only improved service delivery but also a contribution to broader circular economy and climate objectives.

Within a PSS, revenue models define how providers generate income based on different levels of service integration and performance orientation (Van Ostaeyen et al., 2013). According to Van Ostaeyen et al. (2013), depending on how performance is measured, there are many revenue strategies that can be used for every part of a PSS that consists of a product or service, or a combination of both.

The Functional Hierarchy Model (FHM) of Van Ostaeyen et al. (2013), as shown in Figure 2, structures a PSS by linking customer demands to specific functions and solutions. Functions can be categorised in two ways: environment-centric functions, which describe the system's impact on its surroundings, and solution-centric functions, which focus on the technical attributes of the implemented solution (Van Ostaeyen et al., 2013). The model also categorises revenue mechanisms based on performance, usage, availability and input orientation, aligning them with different levels of the FHM.

The first revenue type, Input-Based (IB) revenue, is earned based on the inputs required to deliver a product or service. In product-based models, this typically involves a one-time payment upon ownership transfer, while for services, revenue is based on the resources used, such as labour hours or materials. Availability-Based (AB) revenue, on the other hand, is generated based on the duration a product or service remains available to the customer, regardless of actual usage. Leasing agreements frequently use this concept, in which a fixed cost is paid in exchange for continuous access. Usage-Based (UB) revenue links income directly to how much a product or service is used with charges determined by measurable factors such as time, distance, or frequency. Examples of this model include charging per kilometre driven in a car rental or per operational hour of industrial equipment.

Lastly, Performance-Based (PB) revenue is tied to the functional performance of a product or service. Instead of paying for access or usage, customers are charged based on specific performance outcomes, such as energy efficiency or uptime guarantees. Within the PB model, three sub-types exist, corresponding to different levels of abstraction in the FHM. Solution-oriented revenue is based on solution-specific performance indicators, measuring the system's own performance. Thus, revenue is paid according to the promised performance of the system. Effect-oriented revenue depends on objective environmental effects, independent of the solution. This means that revenue is paid based on the fulfilment of the objective environment-specific functional performance indicators. Demand fulfilment revenue is linked to subjective customer satisfaction. Based on a subjective functional performance indicator that indicates how successfully a customer's demand is met, revenue is generated.

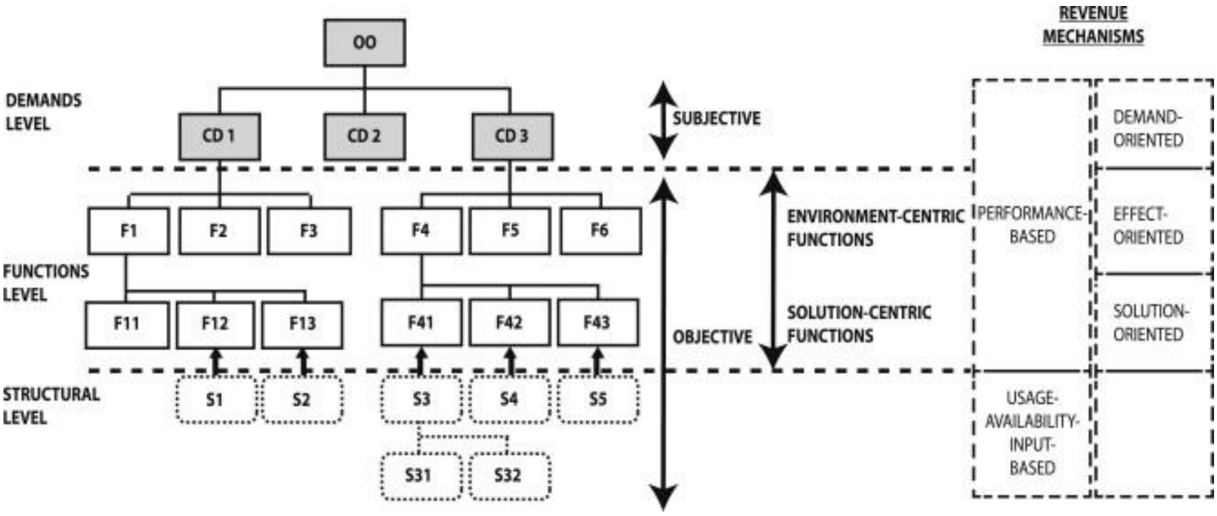


*Figure 2: Relation of the performance orientation of revenue mechanisms and the FHM (Van Ostaeyen et al., 2013)*

The level of integration within a PSS influences which revenue model is applied. For instance, if a car rental service includes a maintenance contract at a fixed daily rate, the service and product components are integrated under a usage-based revenue model (Van Ostaeyen et al., 2013). By structuring revenue models in this way, PSS providers can create financial incentives that promote sustainability while offering flexible and cost-effective solutions for customers. In more performance-oriented PSS models, contractors are granted greater flexibility to propose innovative solutions, encouraging creative thinking and the adoption of sustainable measures that can enhance the overall environmental performance of the project (Van Ostaeyen et al., 2013).

## 2.3 Barriers

### 2.3.1 Financial Barriers

Significant financial barriers hinder the adoption of PSS in the construction industry. One of the primary concerns is the uncertainty surrounding cash flow, as PSS requires medium- to long-term investments (Ceschin, 2013), making it a riskier business model for contractors (Vezzoli et al., 2015). This uncertainty is further exacerbated by the difficulty of quantifying the economic and environmental savings associated with PSS, making it challenging to demonstrate its value to stakeholders (Ceschin, 2013). Furthermore, contractors often struggle with a lack of profitability when using PSS (Annarelli et al., 2016; Inagaki et al., 2022), as poor market performance of products results in low profit margins (de Jesus Pacheco et al., 2019).

Another major financial barrier is the high initial investment required from contractors (Annarelli et al., 2016; Inagaki et al., 2022; Moro et al., 2020). Since these upfront costs are substantial, contractors may be reluctant to commit to PSS, as there is a prevailing perception that the market is unwilling to pay for its added value (Hayles & Kooloos, 2008). This creates a significant barrier, as the financial feasibility of PSS depends on the willingness of clients to recognise and invest in long-term sustainability benefits. Even when companies recognise the potential benefits of PSS, those that are financially successful within their existing business model may be reluctant to transition to a new approach due to the risks and uncertainties involved (Ceschin, 2013; Hannon et al., 2015). This hesitation is particularly evident in small and medium-sized enterprises, which often lack the financial resources necessary to fund PSS implementation (de Jesus Pacheco et al., 2019; Vezzoli et al., 2015).

Another important financial barrier relates to the uncertainty surrounding residual value, particularly for assets with long lifespans (Schraven et al., 2022). The residual value is inherently difficult to predict, as it depends not only on the future condition of the asset but also on market developments and the evolving value of materials at the time of contract completion (Schraven et al., 2022). Contractors face the challenge of estimating how refurbishment potential or material recovery will be valued in the future, a process that currently lacks sufficient historical data and depends largely on experience yet to be gained (Schraven et al., 2022). This lack of clarity regarding residual value complicates contract negotiations and financial planning, discouraging the adoption of PSS models.



### 2.3.2 Organizational Barriers

Implementing PSS requires significant changes in organisational processes, including operational and logistical adjustments, as well as shifts in management and design activities (Moro et al., 2020; Vezzoli et al., 2015). Companies must develop new competencies and expertise to manage the transition from selling products to providing long-term services. This shift also demands a fundamental change in business culture, requiring companies to move from transaction-based models to relationship-driven approaches that emphasise value-in-use rather than one-time exchanges (Annarelli et al., 2016; de Jesus Pacheco et al., 2019). Additionally, organisational inertia presents a significant challenge, as companies deeply rooted in product sales often struggle to adapt to service-oriented models (Hannon et al., 2015). Furthermore, employees may resist these changes, as shifting to PSS alters established workflows and consumption habits (Kuo et al., 2010). This reluctance can create internal opposition, leading to rejection or hesitation among personnel who are accustomed to traditional business practices (Kuo et al., 2010).

### 2.3.3 Behavioural Barriers

While PSS offers significant potential, its adoption in the construction industry remains limited due to various behavioural barriers. One of the key obstacles is the lack of knowledge among both clients and contractors, which hinders the effective implementation of PSS (Schraven et al., 2022; Teigiserova et al., 2023). Without a clear understanding of how PSS works and the long-term benefits it can provide, stakeholders may hesitate to adopt it. Additionally, resistance to change among stakeholders presents a major challenge (Moro et al., 2020), as shifting to a PSS model requires adjustments in established behaviours and business practices (Beuren et al., 2013). Many industry professionals may view this transition as complex or disruptive, leading to scepticism and opposition. Furthermore, known for its conservative and risk-averse nature, the construction industry is notoriously resistant to change (Geng et al., 2023), cultural acceptance is an important barrier (Moro et al., 2020). The uncertainty surrounding PSS implementation, along with concerns about accountability and contractual complexities, could further discourage adoption.

Additionally, there can also be resistance from the customer's side. Many customers are hesitant to embrace consumption without ownership (Moro et al., 2020), as the shift from product ownership to product use requires a fundamental change in mindset (de Jesus Pacheco et al., 2019). Additionally, lack of customer interest in service-based models further slows adoption (Kuo et al., 2010). Another challenge is the requirement for long-term relationships between contractors and clients (de Jesus Pacheco et al., 2019; Inagaki et al., 2022), which some customers may be unwilling to commit to. Unlike traditional contracts, PSS relies on ongoing service agreements, which may be perceived as restrictive or undesirable by clients who prefer flexible, short-term engagements.

### 2.3.4 Regulatory Barriers

A lack of clear regulations, standards, and policies is another major obstacle to PSS adoption. There are no well-defined guidelines for its operation and maintenance, and companies receive little regulatory support to integrate sustainability considerations into their business models (Inagaki et al., 2022). Additionally, government policies often fail to incentivise sustainable business practices, as environmental impacts are not adequately internalised in financial decision-making (Ceschin, 2013; Hannon et al., 2015). This makes it difficult for businesses to justify investments in PSS, as they do not receive financial or competitive advantages for implementing environmentally beneficial solutions. Furthermore, collaboration between key stakeholders, such as policymakers, academia, and industry, is not yet well established, leaving uncertainty about how to effectively support and develop PSS initiatives (de Jesus Pacheco et al., 2019). Without stronger policy frameworks and financial incentives, the transition to PSS remains challenging for many companies.



## 2.4 Conclusion

PSS can offer a promising pathway toward more sustainable business practices by shifting the focus from product ownership to functional value delivery. However, its potential is also tied to the design of revenue models, which play a critical role in aligning financial incentives with environmental goals. There are several types, such as input-based, availability-based, usage-based, and performance-based revenue models, each influencing how value is delivered. As highlighted by Saccani et al. (2024), the way companies set up their revenue models and pricing can strongly influence behaviours and choices that support sustainable development.

While several sectors, such as manufacturing and product-based industries, have made notable progress in adopting PSS, the construction and infrastructure sector remains less developed in this regard and faces its own unique challenges. Existing literature confirms that the implementation of PSS in the construction industry is often hindered by barriers across multiple dimensions—including behavioural, financial, organisational, and regulatory factors. Building on this understanding, this research also examined how these barriers manifest specifically within infrastructure projects, where long asset lifespans, public accountability, and complex contracting environments add further layers of complexity.

By exploring how different revenue models function within infrastructure-based PSS initiatives, this study seeks to provide insights into how such models can contribute to sustainability goals and support wider adoption of circular practices in the infrastructure sector.

# Chapter Three: Research Methods

A well-defined research design ensures the structured and efficient execution of the study. This research will employ four methodologies. First, a preliminary literature review has been conducted followed by multiple case study analysis in combination with stakeholder interviews to gain insights into the implementation of PSS in construction projects. The case studies are taken from The Circular Road Program. Second, the findings from the case study analysis and interviews have been further explored to deepen the understanding of PSS dynamics. Meanwhile, a literature review was conducted, incorporating insights from the previous stages to contextualise the findings within existing academic and industry knowledge. Lastly a workshop was held in which some findings were presented to participants of the interviews to validate and verify their input.

The first sub-question takes a broad perspective, examining collaboration throughout the project lifecycle. The second sub-question then narrows the focus by zooming in on the role of payment mechanisms in driving sustainability. Finally, the third sub-question broadens the scope again to investigate systemic barriers to PSS implementation, capturing both project-specific and sector-wide challenges. Figure 3 illustrates the relationships among the research questions and the methodologies.

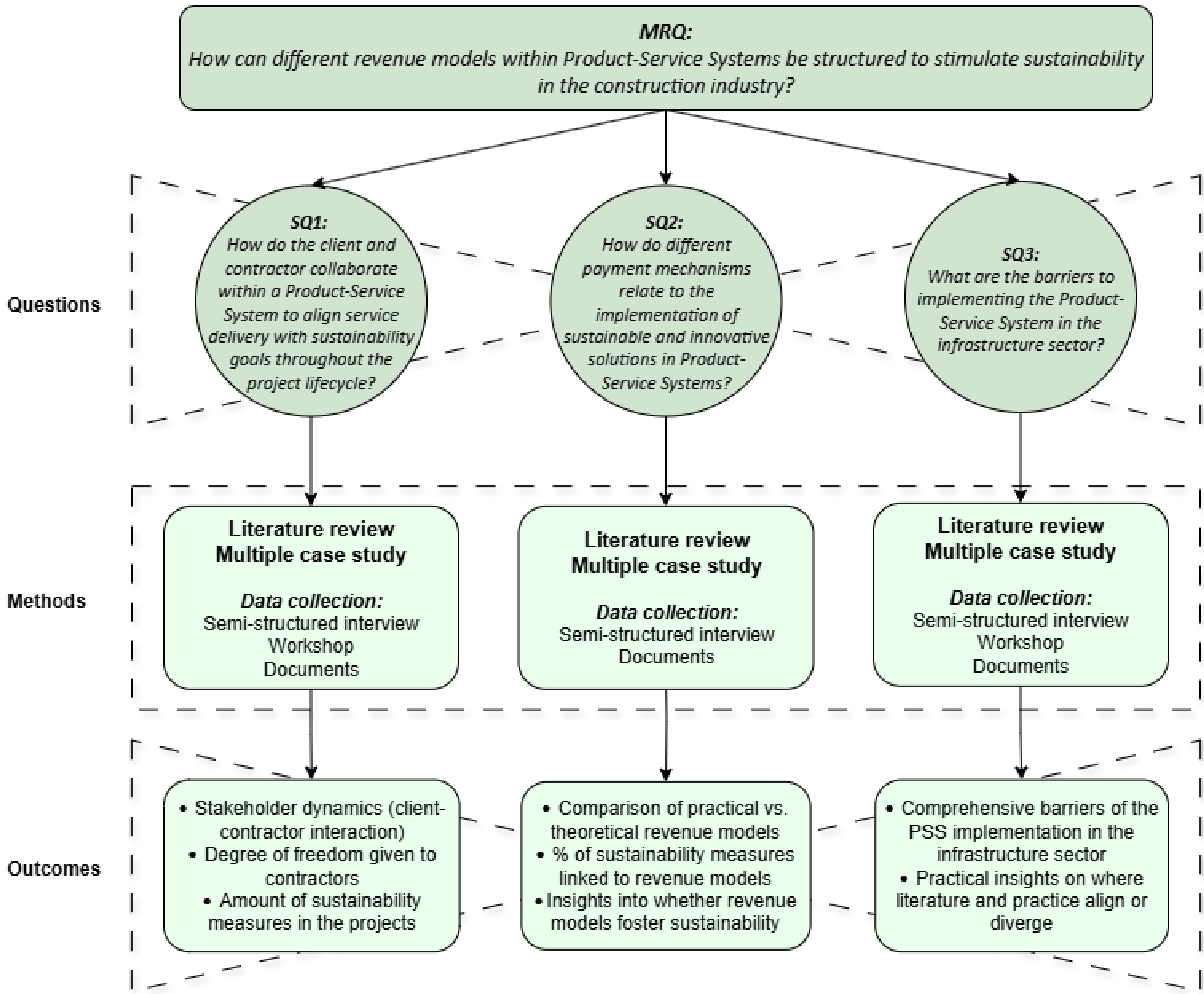


*Figure 3: Flowchart of the methodologies*

## 3.1 Literature Review

The literature review for this research was conducted in two phases. The first phase aimed to establish a theoretical foundation by exploring existing literature on PSS, revenue models in infrastructure projects, and barriers to PSS implementation. This phase provided insight into how PSS contracts function, the financial mechanisms that drive them, and the challenges that hinder their adoption. The literature review also focused on identifying barriers relevant to the construction sector, as this context introduces unique complexities, such as long asset lifespans, fragmented responsibilities, and public accountability, which are less prominent in other industries. The literature research involved sourcing data from academic literature, government reports, and industry documents, ensuring the inclusion of theoretical perspectives and broader industry trends relevant to PSS contracts and barriers. The primary sources included journal articles, governmental or institutional reports and reports from The Circular Road program.

The second phase of the literature review built upon insights from the empirical part of the research. While the barriers were initially drawn from literature, they were revisited and validated during the case studies and stakeholder interviews. The interview findings were used to assess whether these barriers identified in the literature were also experienced in practice, and whether additional practical nuances emerged. This iterative approach enabled a comparison between literature and real-world application, helping to highlight where literature aligns with or diverges from practice in the context of PSS in infrastructure.

The literature search process followed a systematic approach, utilising academic databases such as Google Scholar, Research Gate, the TU Delft repository, Scopus, ScienceDirect, and JSTOR. Keywords and search terms included but were not limited to: “Product-Service System”, "Product-Service System in infrastructure", "performance-based contracts", "sustainable procurement", “construction industry”, “infrastructure sector”, "innovative revenue models", “barriers”, “limitations”, “obstacles”, “collaboration challenges”, “financial risks” & “stakeholder resistance”. Articles were selected based on relevance, credibility, and recency to ensure a comprehensive and up-to-date analysis.

## 3.2 Multiple Case Study Analysis



This research employs a multiple case study approach to examine the dynamics of PSS in real-world infrastructure projects. The case study method is particularly useful for understanding complex interactions within a specific setting (Eisenhardt, 1989). The goal of case study analysis is to investigate an issue that is currently occurring in a real-world situation (Yin, 1981).

*“Case study research is a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information … and reports a case description and case-based themes”*

*(Creswell, 2007, p. 73).*

Multiple case studies is used to either predict similar outcomes in the studies or contrasting findings for anticipated reasons (Gustafsson, 2017). Three categories of case studies are distinguished by Yin (1981): exploratory, descriptive, and explanatory. This study followed an exploratory case study approach to gain insights into the interactions between clients and contractors within PSS contracts, focusing on payment structures and the challenges of implementing sustainable solutions.

The main limitation of the case study approach is that it may result in theories that are too narrowly focused and not generally applicable (Eisenhardt, 1989). Because this method develops hypotheses based on in-depth observations, there is a chance that the results will only be applicable to specific circumstances and not to more broad scenarios (Eisenhardt, 1989). However, by analysing multiple cases within the same program, this research enhances comparability and the identification of recurring patterns, strengthening the validity of its conclusions.

### 3.2.1 Pilots from The Circular Road Program

The Circular Road program is a collaboration between public and private organizations within the infrastructure sector. It includes a wide range of partners, such as government agencies like Rijkswaterstaat and local municipalities, construction firms, engineering consultancy firms, and financial institutions (De Circulaire Weg, 2023). By involving all the key stakeholders in the value chain, the program aims to create and implement a fully circular business model (De Circulaire Weg, 2023). Its focus goes beyond just technical innovations, it also explores new ways of working together, designing contracts, and structuring financial models to promote lifecycle thinking and reduce the use of raw materials (De Circulaire Weg, 2023).

This research drew on both the ongoing work of the second phase, launched in February 2023, and the documents produced during the first phase of the program. In particular, the program report by Schraven et al. (2022) and project descriptions developed in the first phase were used as a key source of secondary data to support and contextualise the case analysis.

The cases analysed in this research were derived from eight pilot projects within The Circular Road Program. Three of the pilot projects were from The Circular Road 2.0 program, while five came from The Circular Road 1.0 program. These projects provided a valuable foundation for exploring how PSS is applied in infrastructure projects, particularly regarding collaboration methods and financial structures. The case studies included a mix of ongoing and completed pilot projects, allowing for an analysis of different phases of implementation. The selected cases are: sustainable road management (province of North Holland), sustainable road lighting (province of North Brabant), temporary road at Arena (municipality of Amsterdam South East), reconstruction of Dr. J. P. Heijerlaan (municipality of Amersfoort), replacement of two bridge decks (municipality of Amersfoort), Rijkswaterstaat A6 (municipality of Almere), Nieuwland public lighting (municipality of Amersfoort) & van Noorderkroon residential street reconstruction (municipality of Veenendaal) (De Circulaire Weg, 2022a). These projects are summarized in Table 2. It is crucial to remember that some of these pilot projects are still in progress and that not all of them have been completed yet. Nonetheless, analysing distinct phases of the pilot program will provide intriguing perspectives on the varied experiences.

*Table 2: Case study projects*

| Project | Province/ Municipality | Status | PSS | Program phase |
|---|---|---|---|---|
| **Nieuwland public lighting** | Amersfoort | AAS design completed, will not continue AAS | No | The Circular Road 2.0 |
| **Noorderkroon residential street reconstruction** | Veenendaal | Planning phase | Yes | The Circular Road 2.0 |
| **Rijkswaterstaat A6** | Almere | Operation and maintenance phase | Yes | The Circular Road 2.0 |
| **Replacement of bridge decks** | Amersfoort | Operation and maintenance phase | Yes | The Circular Road 1.0 |
| **Reconstruction of Dr. J.P. Heijerlaan** | Amersfoort | Operation and maintenance phase | Yes | The Circular Road 1.0 |
| **Temporary road at Arena** | Amsterdam Southeast | Project finished | No | The Circular Road 1.0 |
| **Sustainable road lighting** | North Brabant | Operation and maintenance phase | Yes | The Circular Road 1.0 |
| **Sustainable guiderails** | North Holland | Project finished | No | The Circular Road 1.0 |

### 3.2.2 The Functional Hierarchy Model

To systematically analyse the cases, this research applied the Functional Hierarchy Model (FHM) developed by Van Ostaeyen et al. (2013). The FHM is a framework designed to represent a system's functions and their interdependence with other products, services, or processes within the same customer environment. It consists of three hierarchical levels: customer demands (the core objectives the system addresses), functions (actions or effects required to fulfil these demands), and structural elements (specific products, services, or processes fulfilling these functions) (Van Ostaeyen et al., 2013). As Schraven et al. (2022) have already applied the FHM to four of the completed cases, this study only developed FHM models for the three ongoing cases.

During the stakeholder interviews, both clients and contractors were asked to verify and adjust the FHM for each project. These models serve to clarify how project objectives have been translated into functional requirements and contractual arrangements. However, due to the collaborative and interwoven nature of the client–contractor relationship, the data collection process could not consistently determine which party was responsible for proposing specific measures or contributions within the FHM. As such, the FHMs reflect a collective outcome rather than clearly attributable individual inputs. The FHM was used as an analytical tool to assess stakeholder interactions, determine the degree of freedom granted to the contractor, identify which circular measures have been implemented, and evaluate which revenue mechanism would theoretically be most appropriate, based on the framework proposed by Van Ostaeyen et al. (2013).

### 3.2.3 The Sustainable Measures

To evaluate the integration of sustainability across the pilot projects, this research developed a set of sustainability measures that served as the basis for assessment. The identification of these measures followed a dual approach. First, existing data from the pilot projects, such as stakeholder interviews, case documentation, and the FHMs from Schraven et al. (2022), provided practical insight into which types of measures had already been considered relevant in practice. In particular, the circular measures identified in the original Circular Road 1.0 report served as a starting point for understanding real-world interventions aimed at improving environmental performance.



Second, to validate and refine this list, a theoretical framework based on academic literature was developed. Key value drivers of environmental sustainability in PSS were identified from recent sources, and they were used to cross-check and validate the practical measures derived from the project data. This ensured that each measure on the final list addressed a specific sustainability objective, such as resource efficiency, pollution reduction, or biodiversity conservation. The final list of sustainable measures (shown in Table 4, Chapter 4.9) combines theoretical validation with empirical observations to reflect recognised academic sustainability standards as well as the reality of current infrastructure operations.

While the number of implemented sustainable measures provides a useful indication of how extensively sustainability has been addressed in a project, it does not capture the actual environmental impact of these interventions. For example, a project featuring fewer sustainable measures could still result in a greater reduction in $CO_2$ emissions than one with a larger number of smaller-scale interventions. Therefore, this analysis should be viewed as one lens through which to assess sustainability. To determine the absolute environmental impact and effectiveness of these measures, further research is needed that directly quantifies outcomes such as emissions reduction, material savings, or biodiversity improvements.

## 3.3 Semi-structured Interviews

Stakeholder interviews were used to gain a deeper understanding of the cases and to gather additional insights from individuals directly involved in the projects. Since PSS implementation is complex and context-dependent, semi-structured interviews were employed to allow for both structured questioning and open-ended discussions, ensuring that key themes are covered while providing flexibility for participants to share their experiences in greater depth (Hammer & Wildavsky, 1993). Semi-structured interviews offer the advantage of enabling interviewees to elaborate on aspects that may not have been anticipated by the researcher, leading to a richer understanding of the subject matter. However, they also come with certain drawbacks. Participants may withhold or omit crucial information due to a lack of trust, confidentiality concerns, or the sensitivity of the data being discussed (Hammer & Wildavsky, 1993). Additionally, there is a risk that interviewees may intentionally or unintentionally misrepresent information, either to align with perceived expectations or due to limitations in their own knowledge (Hammer & Wildavsky, 1993). To mitigate these risks, efforts were made to establish rapport and trust with participants, ensuring that they feel comfortable sharing their experiences honestly.

The interviews, lasting between 45 to 60 minutes, were audio-recorded and transcribed for accurate data collection. Moreover, interview summaries were sent to participants for verification, allowing them to confirm or clarify their statements to ensure an accurate representation of their perspectives.

Professionals involved in The Circular Road project who have worked on these case studies have been interviewed as stakeholders to gain firsthand insight into roles, responsibilities and challenges. Interviews have been conducted with three groups of participants, each offering a unique perspective on PSS implementation. Public clients were interviewed to understand the objectives and requirements they set for infrastructure projects, including their role in contract design and revenue model selection. Contractors provided insights into the operationalisation of client demands, including how they translate overarching project goals into functional and technical solutions and challenges of working with a PSS. Consultants provide an objective viewpoint and insights on the organisational, financial, and technical aspects of PSS. Participants involved in past PSS pilot projects, both the client and contractor side, were interviewed to evaluate the effectiveness of different revenue models and identify the challenges they faced. Their experiences helped assess whether PSS models have led to tangible sustainability benefits and whether they are feasible for broader industry adoption.

The semi-structured interviews centred on the stakeholder's experience in respect to the other contracting party. The interviews focused on three key themes: the translation of project objectives into operational decisions, revenue models and sustainability incentives, and barriers and opportunities for PSS adoption. First, the interviews explored how project objectives, as defined by the client, were translated into functional and technical requirements by contractors. This included understanding how overarching goals are operationalised and how the client and contractor interact with one another. The second theme examined the financial structure of the projects, focusing on the revenue model used, how it influenced contractor decision-making, and whether sustainability was incentivised. Finally, the interviews addressed both barriers and opportunities for PSS adoption. This included financial, organisational, regulatory, and behavioural challenges that hinder implementation, as well as potential changes in policy or industry practices that could make PSS a more viable approach in construction.

During the interview, participants were shown the FHM relevant to their project. They had the opportunity to review and adjust the model based on their responses, refining how project objectives were translated into operational and technical decisions. This process ensured that the FHM accurately reflects the contractor’s role in implementing the client's requirements.

A total of 19 interviews were conducted for this research. To ensure a comprehensive understanding of each project, interviews were held with representatives from both the client and contractor sides wherever possible. Specifically, 7 interviews were conducted with public clients, 10 with contractors, and 2 with consultants, who were involved in the projects. Table 3 provides an overview of the interviewees per project. Since some participants were involved in multiple projects, the total number of interviews is lower than the combined number of interviews per stakeholder group.

*Table 3: Overview of the interviews*

| Project | Client | Contractor | Consultant |
|---|---|---|---|
| **Nieuwland public lighting** | 2 | 3 | 1 |
| **Noorderkroon residential street reconstruction** | 1 | 1 | - |
| **Rijkswaterstaat A6** | 1 | 2 | 1 |
| **Replacement of bridge decks** | 1 | 1 | - |
| **Reconstruction of Dr. J.P. Heijerlaan** | 1 | 1 | - |
| **Temporary road at Arena** | 1 | 1 | - |
| **Sustainable road lighting** | - | 1 | - |
| **Sustainable guiderails** | 1 | 3 | - |
| **Total** | 8 | 13 | 2 |

## 3.4 Workshop

Following the interviews, a workshop was conducted with participants from the Noorderkroon residential street reconstruction project, to observe group dynamics, validate the findings from the interview phase, and further explore how co-creation takes place in a practical project setting. The workshop brought together key stakeholders from both the client and contractor sides, many of whom had previously participated in the individual interviews. This setting provided a valuable opportunity to engage with the full project team and to observe their collective response to the concepts of PSS and the Functional FHM applied to their project.

The session allowed for a deeper understanding of how stakeholders interpreted the FHM, how they perceived their own roles and responsibilities within a PSS framework, and the extent to which they were aligned on the project's functional objectives. It also enabled real-time discussion about project constraints, collaboration processes, and the perceived value of service-based approaches.

Due to time constraints and logistical considerations, this workshop was limited to the Noorderkroon project only. While workshops with participants from other pilot projects would have further enriched the findings, the Noorderkroon session nonetheless offered significant insights into the dynamics of co-creation and the practical application of PSS principles. The workshop served as a useful complement to the interview data by enabling observation of stakeholder interactions in a collaborative environment and validating key findings in a group setting.

## Chapter Four: The pilot projects

This chapter presents an in-depth examination of eight pilot projects conducted under The Circular Road initiative. Three of these projects, Nieuwland public lighting, Noorderkroon residential street reconstruction, and Rijkswaterstaat A6, are part of Circular Road 2.0 and are currently ongoing, each situated in different phases ranging from the planning phase to the operation and maintenance phase. The remaining five projects, replacement of bridge decks, reconstruction of Dr. J.P. Heijerlaan, temporary road at Arena, sustainable road lighting, and sustainable guiderails belong to The Circular Road 1.0 program and have already been implemented and are in the operation and maintenance phase or the contract has already finished.

For the ongoing Circular Road 2.0 projects, each project was analysed using a Functional Hierarchy Model developed specifically for this research. The FHM was used to analyse the PSS, the dynamic between the client and contractor and identify sustainable and circular initiatives. For The Circular Road 1.0 projects, the FHMs were already constructed and analysed in detail in the report by Schraven et al. (2022), and therefore were not recreated here. Instead, this chapter includes a post-implementation analysis of the completed projects from the previous program 1.0, identifying key lessons learned, particularly in relation to revenue models and challenges faced during the execution of PSS-based contracts.

### 4.1 Nieuwland Public Lighting – Amersfoort

The municipality of Amersfoort lies in the province of Utrecht and has around 160.000 inhabitants as of 2024 (Centraal Bureau voor de Statistiek, 2024a). Located in the northern part of Amersfoort, the Nieuwland district is bordered by the Rondweg Noord, the A1 highway, and the N199, as shown by the red boundary in Figure 4. This residential district is home to around 14,000 inhabitants (Gemeente Amersfoort, 2023) spans 210 hectares, and has a population density of 6.881 people per km² (Centraal Bureau voor de Statistiek, 2024b).

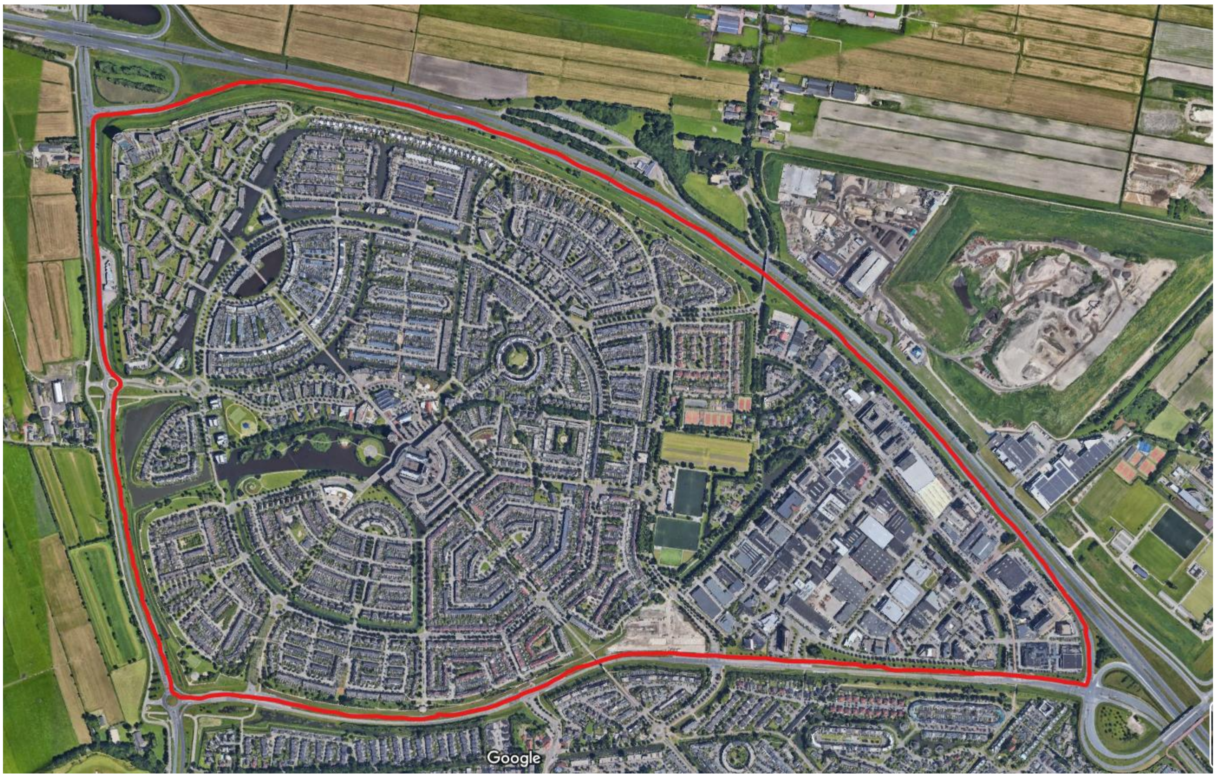


*Figure 4: Area of the Nieuwland district*

### 4.1.1 Pilot Description

The municipality of Amersfoort is undertaking a large-scale replacement of outdated public lighting across the city. These fixtures primarily consist of fluorescent lamps that contain mercury, a hazardous substance that must be phased out due to environmental regulations. In total, approximately 20,000 lamps are slated for replacement. The initiative is divided into multiple phases, with the Nieuwland district serving as the first. In this phase, 2,852 luminaires and 2,641 pylons will be upgraded. The project goes beyond simple replacement; it aims to achieve a comprehensive and sustainable redesign of the entire public lighting system in the district.

Initially, the municipality considered applying a PSS approach. Since not all lighting units had reached the end of their technical lifespan, the idea was to allow replacements to occur gradually, with fixtures being renewed only when necessary. The service-based approach was intended to improve resource efficiency and promote sustainability. To assess the feasibility, the municipality conducted a market consultation involving six contractors. These contractors were asked whether they had prior experience with PSS, how they would apply such a model within the context of public lighting, and what preferences they had regarding the tendering process. The goal of this consultation was to understand both the operational feasibility and the practical implications of service-based contracting in this domain.

However, due to the technical sensitivity of the lighting system, the contractors expressed significant concerns. They indicated that staggered replacement would introduce operational risks, particularly the need for near-daily inspections to verify lamp functionality. This high monitoring frequency would result in increased maintenance costs and logistical challenges. As a result, the contractors strongly preferred replacing all lighting fixtures in one phase.

Based on the outcomes of the market survey and subsequent internal evaluations, it was concluded that, given the specific nature of the pilot, applying the PSS model posed significant challenges. As a result, the decision was made not to proceed with a PSS framework for this pilot.



### 4.1.2 The Product–Service System for Nieuwland Public Lighting

A PSS can be translated into a FHM, which maps the system's key functions and illustrates the means–end relationships that connect customer demands to functional and structural solutions (Van Ostaeyen et al., 2013). The FHM provides a useful framework for analysing and differentiating between types of PSS by breaking down the system into three hierarchical levels. At the highest level are customer demands, which reflect the overarching goals and sub-goals of the client. The functional level represents the system's desired functions, which can be either effect-oriented or solution-oriented. At the base is the structural level, which has components and tangible solutions made to meet the functional requirements.

Figure 5 shows the FHM developed for the Nieuwland public lighting project. In this model, responsibilities have been colour-coded: the client (the municipality of Amersfoort) is shown in blue, and the contractor (still to be selected) is shown in yellow. It is important to note that this FHM is not based on a finalised design or contract, as the project is still in a preparatory phase. Rather, it is a conceptual model constructed from insights gathered during interviews with the participants of the market survey (contractors) and the client. The model reflects how the system could be structured if a PSS approach is adopted. However, not all components have been fully defined, as many elements remain under development due to the project being in its preparatory phase. The FHM, therefore, serves as an illustrative scenario for how the demands, functions, and potential structural level components can be structured in the future tender and contract.

The overarching objective of the Nieuwland public lighting project is to explore the use of alternative contract forms, specifically PSS, to advance circular ambitions in the replacement of public lighting. As shown in Figure 5, this overall goal is supported by five key sub-objectives: ensuring aesthetic quality, securing light quality, enabling upscaling, achieving sustainability, and exploring the potential for a multi-year maintenance contract. These sub-goals have been further translated into functional and structural components across the different levels of the FHM.

Aesthetic quality is shaped by two main considerations: the lighting system must align with the municipality's spatial quality framework, and it must remain manageable after the contract ends. The municipality refers to its internal quality guide for public space (KOR) to ensure visual consistency in public environments. The requirement for post-transfer manageability ensures that the system is compatible with existing municipal practices and maintenance capabilities.

Light quality is also a critical demand, subdivided into the adequacy and availability of light. The functional requirement for providing the right amount of light involves delivering appropriate lighting levels that adapt to time of day or activity. Contractors interviewed suggested that this can be achieved using a dynamic management package that enables remote control of lighting fixtures. These systems allow luminaires to adjust brightness in response to environmental triggers, such as motion detection, optimising energy use and comfort. To ensure availability of light, the goal is to minimise disruptions and resolve any incidents promptly. Contractors suggested digital maintenance platforms such as MOON or Luminizer, which enable the municipality to report disruptions directly into a central system. This information is then relayed to the contractor, who can dispatch a mechanic to resolve the issue.

A third project ambition is upscaling. Unlike previous PSS pilots that involved pre-selected contractors from The Circular Road program 1.0, the Nieuwland project aims to broaden participation through a competitive tendering process. This approach is intended to test whether the PSS model can be generalized and replicated at scale. To support this, a lessons learned document will be compiled to capture insights from the pilot and guide future initiatives.



The overarching goal of the project already reflects the ambition to realise circular outcomes, with sustainability identified as a key sub-goal. This objective is articulated through two main demands: achieving a low MKI (Environmental Cost Indicator) and reducing energy consumption. The MKI is influenced by both $CO_2$ emissions and the use of raw materials. To lower emissions, contractors proposed using electric vehicles for maintenance activities, including electric aerial work platforms. Additionally, municipal compliance with the Handbook for Public Space Design (HIOR) plays a guiding role, as it outlines requirements concerning materials and elements used in public space construction, which in turn affects material sourcing and sustainability performance.

To reduce raw material usage, one of the contractor-proposed solutions involves recycling lighting masts by returning them to the manufacturer. This process allows the masts to be refurbished and later reused, potentially by other contractors. Alternatively, refurbished masts can be purchased directly, although this option involves notable additional costs. In terms of energy consumption, the municipality expressed a preference for deferring to contractor expertise but did note that lower energy use would benefit the contractor as well, particularly when they are responsible for maintenance. Efficient luminaires, such as LED armatures, were identified as a potential solution for minimising energy usage while maintaining high performance.

Lastly, the municipality is considering the use of a multi-year maintenance contract. While not yet fully defined, this ambition signals an interest in longer-term partnerships with contractors, potentially enabling better planning and lifecycle optimisation.

This FHM does not reflect a finalised contract structure but is based on interview insights from contractors during a market consultation. As such, the system remains indicative and exploratory, offering a conceptual foundation for how the project could be structured under a PSS framework.

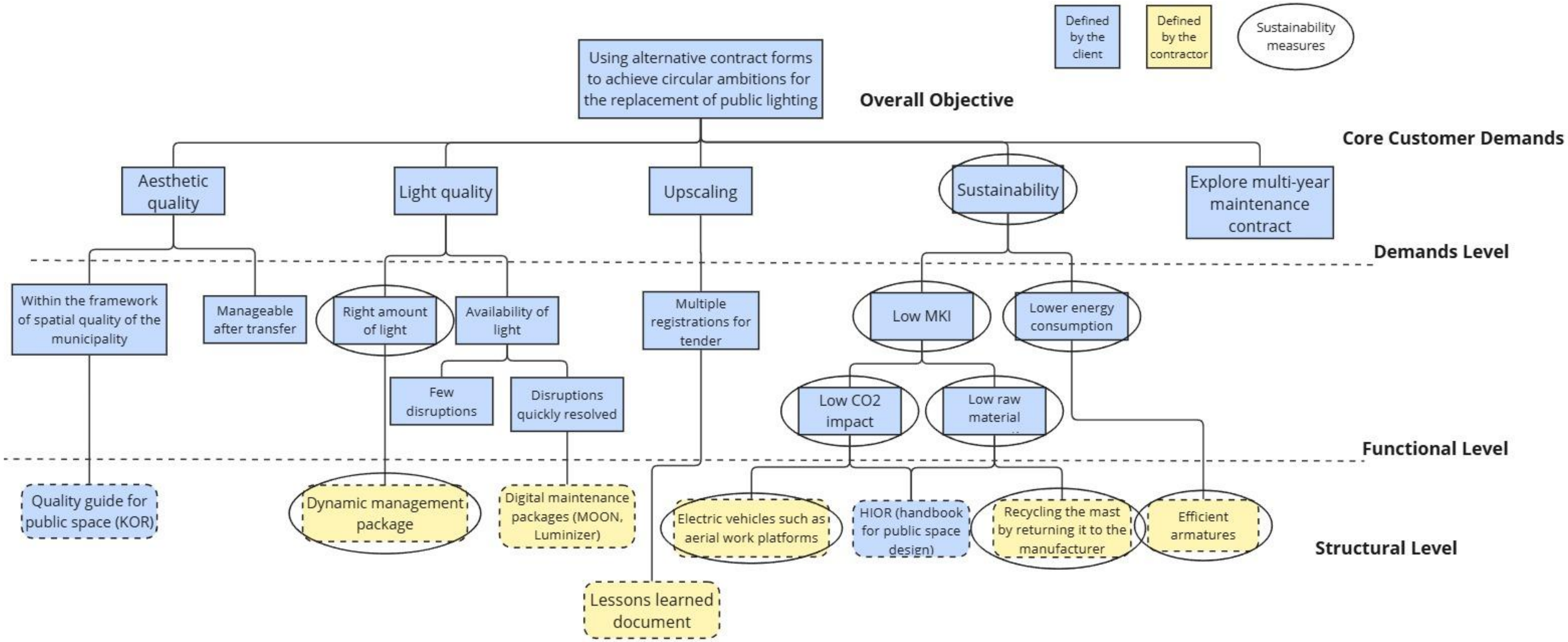


*Figure 5: The Functional Hierarchy Model of the project Nieuwland Public Lighting*
*Based on the theory of Van Ostaeyen et al. (2013). A distinction is made between the input from the client (in blue), the contractor (in yellow). The encircled elements are defined as factors that contribute to sustainability.*

## 4.2 Noorderkroon Residential Street Reconstruction – Veenendaal

Veenendaal, a municipality located in the province of Utrecht, has approximately 69,000 residents (Centraal Bureau voor de Statistiek, 2024a). The Noorderkroon is an asphalt road with sidewalks on both sides, situated on the east side of Veenendaal in the Dragonder district. This road curves around the area and features several smaller connecting streets branching outward. The Noorderkroon itself is home to approximately 350 residents and contains 105 houses (AlleCijfers, 2023). The area covered by the Noorderkroon is highlighted in Figure 6, where the red line outlines the project's scope. The houses in the Noorderkroon are all owner-occupied properties.

*Figure 6: Area of the Noorderkroon*

### 4.2.1 Pilot Description

The Noorderkroon in Veenendaal is being reconstructed to separate the currently combined sewer system, which collects both rainwater and wastewater in a single pipe. Additionally, the road surface has deteriorated and reached the end of its service life, making reconstruction necessary. The municipality aims to redesign the public space as sustainable and circular as possible. This involves using recycled or renewable materials that are easier to reuse in the future, differing from standard material choices.

Ballast Nedam has been awarded the contract and is currently working on the project in a *bouwteam* (early contractor involvement) setting. The design phase is currently ongoing, and residents are being involved through a participatory process. Although the intention is for the contractor to also take on the maintenance phase, this has not yet been formally confirmed.

The project emphasizes knowledge development across three themes: integral value, shifting roles, and residual value determination. Integral value goes beyond financial gains and includes social and ecological value creation, monitored through an integral value tool. The shift in roles reflects the contractor's extended responsibility, from realisation to the maintenance period, promoting long-term collaboration with the client. Lastly, residual value determination focuses on objectively assessing the remaining value of the infrastructure at the end of the contract.

### 4.2.2 The Product–Service System for Noorderkroon Residential Street Reconstruction

The overarching objective of the Noorderkroon pilot project is to transform the district into a circular and sustainable area. Both the municipality and the contractor stressed that achieving sustainability alone is not sufficient, circularity is also central to the project's ambitions. To achieve this, five sub-goals have been established: knowledge development, greening, disconnection of the rainwater drainage system, sustainability and maintenance. Sustainability includes two requirements: circularity and climate adaptation. Figure 7 illustrates the core components of the Product-Service contract. It clearly differentiates between elements defined by the client (in blue), element defined by the contractor (in yellow), and those developed jointly (in grey).

The knowledge development component of the Noorderkroon project focuses on learning from the project's approach to be able to inform future initiatives. Three key knowledge areas have been identified: integral value, shift in roles, and residual value. Integral value refers to a broader interpretation of value creation, which includes not only financial but also social and ecological aspects. Shift in roles highlights the evolving relationship between client and contractor in a long-term collaboration, where responsibilities extend beyond the construction phase. Residual value concerns the remaining worth of the assets at the end of the contract period. Together, these themes serve as drivers for embedding sustainability within the project framework.

Greening the neighbourhood is a priority of the Noorderkroon project, motivated by the current imbalance between paving and green space. This will be addressed through two main strategies: planting additional trees and greening the courtyards. The municipality aims to achieve a 40% shadow effect within 15 years, which will be made possible as the trees mature and their canopies expand. Additionally, the project targets a 10% reduction in paved surfaces across the district. This is considered feasible, particularly in the courtyards where green elements can be integrated without major functional disruption. However, the design must accommodate the passage of a 16-meter reference vehicle, which imposes constraints on the extent of greening that can be implemented.

One of the primary drivers behind the reconstruction of the Noorderkroon district is the municipalities ambition to separate the rainwater drainage system from the existing combined sewer system, which currently manages both rainwater and wastewater. This objective will be addressed through two main interventions, one of which is disconnecting the street and the individual homes from the combined sewer system. To support this transition, a dedicated rainwater sewer system will be installed. Additionally, the project aims to expand the area's water retention capacity by increasing the surface water area. As the project is still in the design phase, no specific technical requirements have yet been established for how these measures will be implemented.

The sustainability objective in the Noorderkroon project is shaped by two core demands: circularity and climate adaptation. The push for climate adaptation is driven by the municipality's aim to reduce life cycle costs compared to standard materials, with the requirement that the construction must have a minimum lifespan of 60 years. Circularity, on the other hand, is evaluated based on two criteria: the recyclability of materials and the Environmental Cost Indicator (MKI). These indicators are influenced by the materials chosen for the project, which are selected collaboratively by the municipality and the contractor to meet both performance and sustainability targets. Specific structural requirements include the ability of the pavement to endure at least 1,500 motor vehicles per day and to meet load class E600 standards. Additionally, compliance with Dutch nitrogen regulations is necessary, as this will directly affect the MKI score of the materials used.

The demand for availability in the Noorderkroon project is closely linked to minimizing maintenance needs, ensuring that the district remains accessible and functional for residents. To achieve this, the contractor focuses on selecting durable and sustainable materials that reduce the need for frequent upkeep. These material choices form the basis for developing an optimal maintenance strategy tailored to the project. Additionally, the contractor seeks involvement in the sketch design phase to help guide material selection, aligning construction choices with long-term maintenance goals.

The contract is designed to encourage circular initiatives while allowing the contractor the freedom to propose innovative solutions. Since the project follows an early contractor involvement approach, decisions are made collaboratively. The contractor presents several options, which are then jointly evaluated to determine the most suitable solution. This close cooperation also extends to discussions about the maintenance strategy. However, it has not yet been decided whether the contractor will ultimately be responsible for the maintenance, as the municipality already has existing agreements with other parties that maintain the surrounding areas and could potentially take on this role as well.

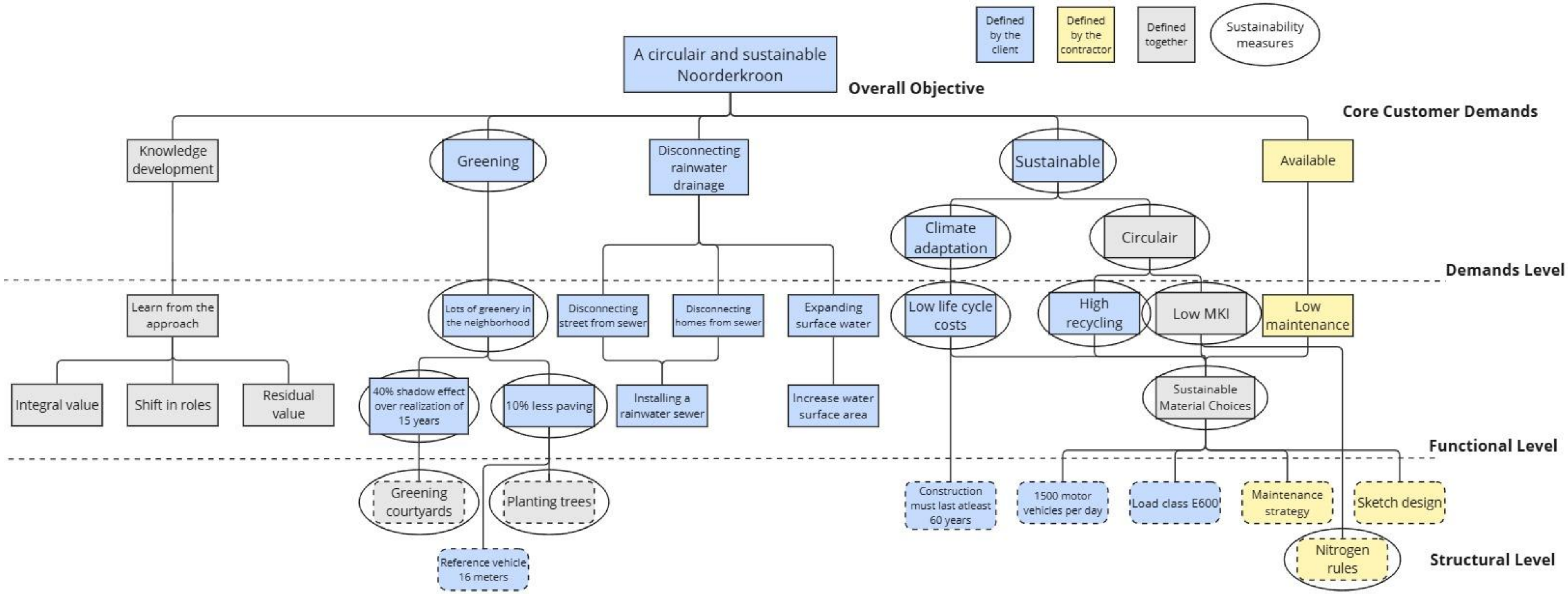


*Figure 7: The Functional Hierarchy Model of the project Noorderkroon*

*Based on the theory of Van Ostaeyen et al. (2013). A distinction is made between the input from the client (in blue), the contractor (in yellow) or from both of them (in grey). The encircled elements are defined as factors that contribute to sustainability.*

### 4.2.3 Validation Through Workshop

During the workshop, the FHM created from the interview data was presented to the group. This allowed participants to assess both the content of the model and the process by which it was developed. Aside from minor discussion on the categorisation of a few elements across the model's levels, the group confirmed the accuracy and relevance of the framework. This validation suggests that not only the model itself, but also the approach used to construct it, drawing directly from structured interview insights, is suitable for capturing the essential structure of a PSS in practice.

In addition to confirming the FHM, the workshop also reinforced the barriers identified in the research. Many of the questions raised by participants during the discussion echoed the financial, organisational, and behavioural challenges presented in Chapter Six: Barriers to Implementing Product Service Systems. The fact that these barriers emerged unprompted in the group's dialogue suggests that they remain pressing and unresolved in the current context of implementation.

The workshop also provided insight into the nature of co-creation in a service-based setting. Although the FHM was intended as a starting point for collaborative discussion, its abstract format required further clarification, indicating that the model, while useful, may need adjustments to be more accessible in practical applications. Furthermore, while participants were highly engaged and eager to identify solutions to key challenges, much of the discussion was directed toward the facilitator rather than peer-to-peer. There was limited spontaneous interaction among stakeholders aimed at jointly shaping the project or developing next steps. This observation highlights a need for more structured facilitation and support in the co-creation process, suggesting that future PSS efforts could benefit from clearer guidance or tools to foster more effective collaboration.

## 4.3 Rijkswaterstaat A6 – Almere

The Rijkswaterstaat A6 project Parkway is a Design, Build, Finance, and Maintain (DBFM), a type of PSS, project located in Almere that is part of a broader initiative to improve accessibility in the greater Amsterdam area. This initiative includes the expansion of key highways connecting Schiphol (A9), Amsterdam (A10), and Almere (A6). The project focuses on increasing road capacity, enhancing traffic flow, and improving the quality of life for local residents. The area covered by the A6 project is shown in Figure 8, outlining the scope of the construction and improvements.


*Figure 8: Area of the Rijkswaterstaat A6 project*

### 4.3.1 Pilot Description

In 2016, the Parkway6 consortium secured the contract for the Rijkswaterstaat A6 project through a public-private partnership. The project involved the design, construction, financing, and maintenance of 13.5 kilometres of motorway under a 20-year operational concession. The main improvements included widening the A6 from two to four lanes in both directions, renovating interchanges, and upgrading bridges and viaducts to enhance traffic flow and accessibility. Construction began in 2017 and was completed in mid-2019, with the newly expanded A6 between Almere Havendreef and Almere Buiten-Oost opening a year ahead of schedule in July 2019.

The Parkway6 consortium responsible for the project consists of Dura Vermeer Groep NV, Besix Group SA, RebelValley BV, and John Laing Investments Limited. Under the DBFM contract with Rijkswaterstaat, Parkway6 is responsible for designing, constructing, and pre-financing the project, as well as managing and maintaining the highway for 20 years after its completion.

Although the Rijkswaterstaat A6 project was already completed before joining The Circular Road program, the maintenance phase has been since included as a pilot. The aim is to make the A6 maintenance strategy more circular and sustainable. While DBFM contracts already reflect aspects of infrastructure-as-a-service, they often lack an explicit focus on sustainability and circularity. This pilot seeks to explore how those elements can be better integrated into long-term maintenance practices.

### 4.3.2 The Product–Service System of Rijkswaterstaat A6

The central aim of the A6 pilot project is to determine a sustainable maintenance strategy and explore circular incentives for the maintenance strategy that can be developed and applied within a DBFM contract. Figure 9 presents the FHM for this project, distinguishing the source of each element using colour: blue for objectives defined by the client, yellow for those defined by the contractor, and grey for elements jointly established.

The project is structured around four key sub-goals: sustainability, safety, road availability, and achieving a qualitative road. Notably, safety is considered a prerequisite for road availability, meaning that ensuring a safe road environment is essential for maintaining continuous access and minimizing disruptions. Each sub-goal is supported by specific functions and structural solutions that together form the foundation for meeting the overall objective of circular innovation in long-term infrastructure maintenance.

In the A6 pilot project, sustainability is positioned as the most important theme and is directly aligned with the overarching objective of developing and applying circular incentives within a DBFM contract. Sustainability is operationalized through a set of targeted measures that aim to lower $CO_2$ emissions and minimize the MKI. Furthermore, reducing material consumption is also looked at by using fewer primary materials and using more recycled materials These goals are pursued through the implementation of specific strategies identified and proposed by the contractor, Dura Vermeer.

A total of thirteen potential measures were evaluated, with the consultancy Rebel assessing their impacts on both $CO_2$ emissions and MKI scores. Out of these, five measures were selected for implementation, as they demonstrated a positive environmental effect and simultaneously led to cost savings, eliminating the need for additional financial incentives such as MKI bonuses Two additional measures also showed promising sustainability benefits but would only be financially viable with an extra MKI bonus As these concern relatively small amounts, they could still be included in the maintenance strategy at a later stage. However, since no final decision has been made, these measures are not included in the FHM.



The five selected measures each contribute to sustainability in distinct ways. The use of 60% recycled material in ZOAB asphalt mixtures reduces primary material use and environmental impact. Ecopave XL, a modified bitumen, extends asphalt lifespan by 1.5 times, lowering replacement frequency and material use. Low temperature asphalt, produced at 140°C, reduces energy consumption and $CO_2$ emissions. Longdot road marking uses a biobased material in a resource-efficient pattern, cutting both material use and emissions. Lastly, the optimal asphalt replacement strategy aligns maintenance with asset lifespan instead of contract duration, improving long-term resource efficiency. Collectively, these measures ensure that sustainability is embedded across the functional and structural levels of the project, effectively lowering environmental impact while maintaining long-term road quality.

In the A6 pilot project, safety is closely connected to the core objective of road availability. Keeping the road safe for users is essential to ensure continuous access and to minimize disruptions caused by incidents or closures. To achieve this, several safety measures have been implemented, including the installation and maintenance of road signs and guide rails. One example is the use of longdot road markings, a biobased and resource-efficient alternative to traditional thermoplastic markings. While this innovation mainly contributes to the project's sustainability goals by reducing material consumption and environmental impact, it also improves safety through enhanced visibility and durability. The integration of such measures illustrates how safety and sustainability can complement each other, supporting the overarching goal of applying circular incentives within a DBFM contract.

Road availability in the A6 project is achieved through a combination of ensuring road safety and optimizing the asphalt maintenance strategy. As shown in the FHM figure 9, safety is treated as a prerequisite for availability, while effective maintenance plays a direct role in minimizing road closures and reducing lost vehicle hours (VWU). A key element in this approach is the use of an optimal asphalt replacement strategy, which is based not on the duration of the contract but on maintaining the asset's value over time. This strategy supports more efficient, timely interventions that extend the lifespan of the road surface. Additionally, the reference maintenance strategy serves as a framework to ensure that sustainability measures align with required or desired quality levels. In this way, the project maintains high road availability while embedding circular practices in the maintenance process.

Lastly, delivering a qualitative road is an essential objective in the A6 project. The contractor is required to meet specific quality requirements defined by the client, which serve as benchmarks to ensure the road remains in good condition throughout the maintenance period. These requirements are directly tied to performance-based incentives. If the standards are not met, such as in cases of excessive road wear, periodic payments may be withheld or stopped. While the project encourages the contractor to explore innovative and more sustainable maintenance strategies, these efforts must always operate within the boundaries of the agreed-upon quality criteria. This balance ensures that experimentation with circular measures does not compromise the long-term performance and safety of the road.

The A6 project originally began as a DBFM contract before it was selected as one of the pilot projects under The Circular Road Partner Program. By the time the project joined the program, the realization phase was already underway. As a result, the focus of the pilot shifted to applying the IAAS principle specifically within the maintenance phase. This opened up opportunities to explore a wide range of sustainability measures, from which five were ultimately selected for implementation based on their positive impact on $CO_2$ emissions and MKI, as well as their cost-effectiveness. Although the maintenance phase officially began in 2019, the evaluation and selection of these measures took place in 2025, and their implementation is set to follow. While the contractual maintenance period runs through 2039, the environmental impact of the selected measures has been projected over a 50-year period until 2068, providing long-term insight into their sustainability benefits. These measures will be periodically reassessed and adjusted, with the possibility of adding new measures in the future. The intention is for this pilot to serve as a learning model for similar projects, offering a practical example of how circular strategies can contribute to significant reductions in $CO_2$ emissions and MKI over the lifecycle of infrastructure assets.

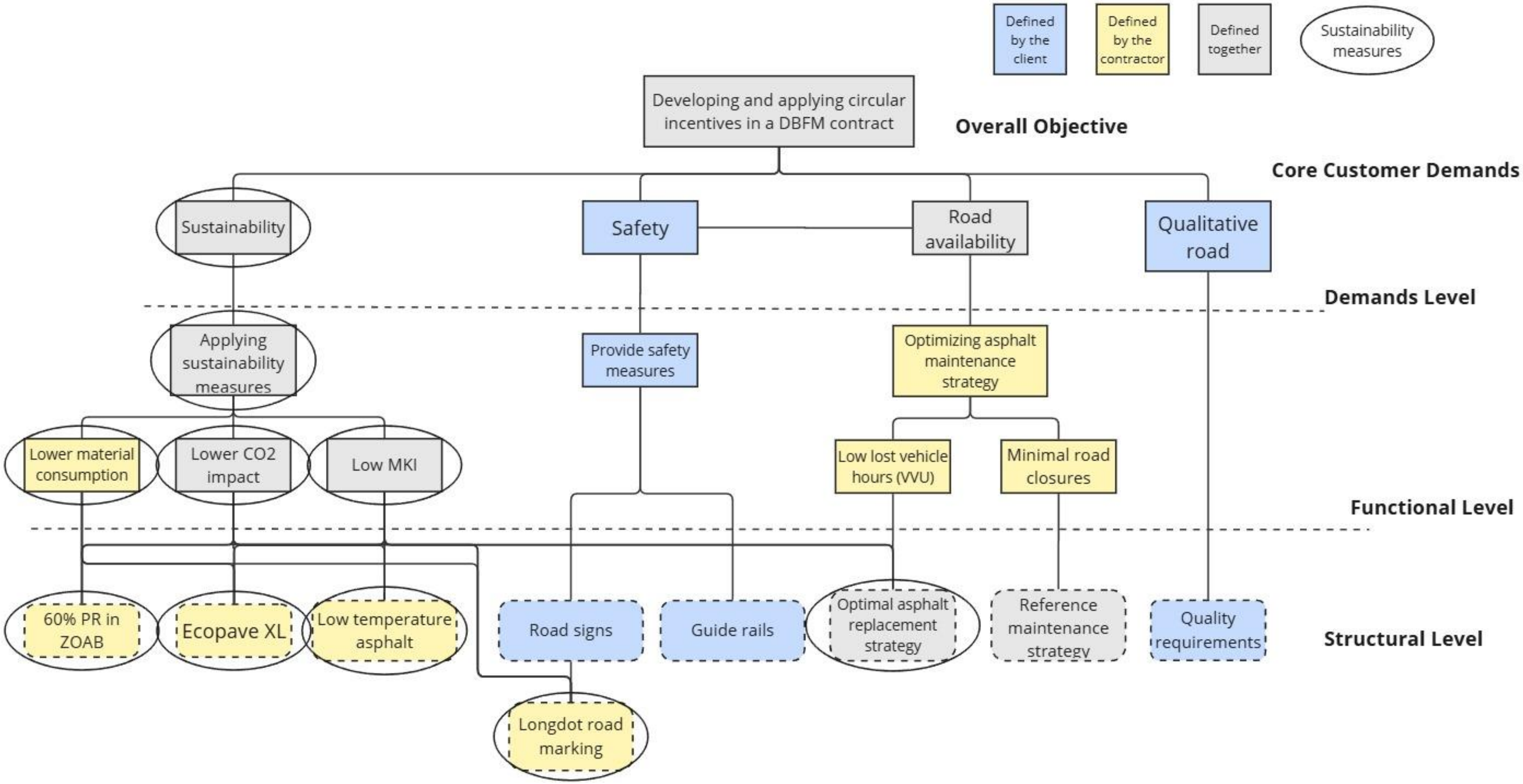


*Figure 9: The Functional Hierarchy Model of the project Rijkswaterstaat A6*
*Based on the theory of Van Ostaeyen et al. (2013). A distinction is made between the input from the client (in blue), the contractor (in yellow) or from both of them (in grey). The encircled elements are defined as factors that contribute to sustainability.*

## 4.4 Replacement of Bridge Decks – Amersfoort

The Watersteeg is a busy five-meter-wide cycling route running through the Nieuwland district in Amersfoort (De Circulaire Weg, 2022a). The slow traffic bridge decks along this route, which cross various waterways, were in poor condition. The wooden planks were affected by wood rot, compromising both comfort and safety for cyclists. Users frequently reported discomfort while riding and noted noise issues caused by loose, rattling planks. As part of The Circular Road 1.0 program, this pilot project focused on removing and replacing the deteriorated bridge decks with more durable materials (Schraven et al., 2022). The bridges are primarily used by pedestrians and cyclists and are not intended for vehicle traffic, except for maintenance and emergency vehicles. The bridge decks were replaced and any essential maintenance was performed throughout the brief two-year contract. The project is still in the contractual stage, but it is nearly completed, following which a valuation and value transfer will take place.

The IAAS model was applied in this project, wherein Dura Vermeer was responsible for selecting and installing a more durable and sustainable decking material. Following thorough research, the contractor determined that tropical hardwood was, in this case, the most sustainable and long-lasting option available. The project also employed an open-book financial model, fostering transparency and collaborative decision-making between the contractor and the municipality. This approach allowed both parties to openly discuss costs and identify efficient, value-driven solutions.

Although public participation was initially explored, it was ultimately deemed unnecessary given the limited impact of the bridge upgrades on the surrounding community. The main project objective was to improve riding comfort and reduce noise pollution, and this was addressed effectively through material replacement. A key consideration for the municipality was the optimisation of the business case, particularly in balancing material choice, environmental impact, and bridge lifespan (Schraven et al., 2022). The project explored the feasibility of reusing the old wooden planks for pedestrian paths. Rather than discarding the old wooden planks from the cycling paths, the contractor repurposed them for the pedestrian paths. By planing and flipping the planks, they were given a second life, reducing the need for new raw materials and enhancing the circularity of the project.



## 4.5 Reconstruction of Dr. J.P. Heijerlaan – Amersfoort

The Dr. J.P. Heijerlaan is a residential street located in the De Berg Zuid neighbourhood of Amersfoort. The road, which runs from the Stichtse Rotonde to the Potgieterlaan, was in poor condition and required reconstruction. Due to its location within a protected cityscape, special attention was given to maintaining the area's character during the project. (Schraven et al., 2022). This reconstruction was part of The Circular Road 1.0 program and aimed to test the IAAS contract model over the course of one year. In this pilot project, Dura Vermeer took on the role of road manager, assuming responsibility for the road availability, maintenance, user comfort, and high-quality reuse of materials after the road's lifecycle (De Circulaire Weg, 2022a). The reconstruction consisted of not just the road and pedestrian paths, but also the public lighting. Instead of following a traditional project delivery model, the municipality of Amersfoort leased the road's availability through a fixed monthly payment (De Circulaire Weg, 2022a). This service-based approach shifted long-term responsibilities to the contractor, encouraging a focus on sustainable maintenance and resource efficiency.

The reconstruction of the Dr. J.P. Heijerlaan in Amersfoort encountered an unexpected challenge during the design phase. Initially, the project team, based on sustainability assessments, opted for an asphalt surface, which was also the material used for the existing road. Asphalt was considered the most environmentally appropriate and technically suitable solution for the location. However, the team later discovered that this design conflicted with municipal aesthetic regulations, which required the use of paving stones to preserve the historic character of the district. Both the contractor and the municipality had assumed the other party would secure the necessary permit for the asphalt option, resulting in the oversight going unnoticed. When the permit was ultimately denied, the design had to be revised to incorporate paving stones, causing delays in the project timeline.

## 4.6 Temporary Road at Arena – Amsterdam

In the southeast of Amsterdam, near the Johan Cruijff Arena, a temporary road called The Passage was constructed to redirect traffic during the development of the Smart Mobility Hub, a large, multifunctional logistics centre designed to improve city accessibility while reducing car traffic (De Circulaire Weg, 2022a). The road, expected to be in use for three to five years, offered a unique opportunity for the municipality of Amsterdam and Dura Vermeer to experiment with circular construction methods under an existing framework agreement.

The project's central aim was to explore how far circular principles could be integrated into a road's full lifecycle, from construction to deconstruction, emphasizing maximum material reuse and minimal environmental impact. Inspired by Amsterdam's "City Doughnut" model, the design prioritized locally sourced, recycled materials and the ability to fully reclaim the road after its temporary use. The municipality was determined to push its sustainability ambitions as far as possible, fully aware that such an experimental approach might result in setbacks. As they put it, "if nothing goes wrong, we haven't gone far enough." With that mindset, the road was constructed to be 100% circular: a new asphalt mix was developed using waste materials from Tata Steel for the surface layer, while bitumen was created from recycled roofing from Ajax's former training complex.

However, the use of recycled components introduced certain technical challenges. Cracks began to appear in the asphalt surface not long after the road was put into use. The exact cause of these defects remains uncertain, but several contributing factors have been identified. The weather during construction was perhaps a problem because it was raining heavily when the asphalt was being poured. Additionally, the road was primarily used by heavy construction traffic, which placed a greater load on the surface than initially anticipated for a temporary road. Moreover, the asphalt itself was made with a high proportion of recycled materials, including reused bitumen, which tends to result in a stiffer, less flexible mix. This reduced flexibility can make the asphalt more prone to cracking under stress. Nonetheless, the contractor addressed the issue under warranty at no extra cost. Despite the challenges, the project provided valuable insights into the performance of circular materials and served as a daring test case for sustainable urban infrastructure.



## 4.7 Sustainable Road Lighting – North Brabant

In North Brabant along the N279, a provincial road between 's-Hertogenbosch (the provincial capital) and Veghel, Dura Vermeer and Hoeflake implemented a sustainable public lighting solution as part of The Circular Road 1.0 program (De Circulaire Weg, 2022a). his initiative operates under an IAAS model, the contractors retained ownership of over 400 light poles and leased the lighting them to the province for a fixed quarterly fee, while being responsible for maintenance and uninterrupted operation (De Circulaire Weg, 2022a). The primary objective of the project was to reduce environmental impact and operational costs through improved energy efficiency (Schraven et al., 2022). The IAAS contract incentivized the contractors to optimize performance and sustainability, with a contractual target of achieving at least 50% energy savings without compromising road safety.

Interestingly, the idea for implementing intelligent and sustainable lighting preceded the province's participation in The Circular Road program and originated from the contractors themselves. Initially, the lighting system had already undergone maintenance as part of a standard provincial contract. When the new concept for dimmable lighting emerged, the fixtures had to be revisited and modified, essentially undergoing maintenance twice, which resulted in additional costs. While the operation phase had not originally been developed under an IAAS framework, the adjustments needed to enable dimming capabilities were later incorporated into such a model. The project was characterized by early contractor involvement and open-book financial transparency, allowing the province and contractors to collaboratively explore the technical and financial viability of more sustainable lighting solutions.

## 4.8 Sustainable Guiderails – North Holland

In recent years, the province of North Holland has taken active steps to make its infrastructure more sustainable. One of these initiatives is a pilot project focused on circular road management, conducted by Dura Vermeer, the company responsible for maintaining provincial roads in the northern region (De Circulaire Weg, 2022b). The project centres around the renovation of guide rails in Den Helder along a stretch of the N250, between kilometre markers 113.350 and 115.500 (Schraven et al., 2022). These roadside elements have a significant environmental footprint, mainly due to the use of steel and zinc in their production (Schraven et al., 2022). Traditionally, guide rails nearing the end of their service life are replaced entirely. However, this pilot explored a more circular alternative: guide rails were to be inspected, removed before full deterioration, re-galvanized, and then reinstalled with the same technical quality as new ones. The aim was to extend their lifespan while reducing material use and associated $CO_2$ emissions. Additionally, the project served to evaluate the potential for IAAS principles in public infrastructure projects, with attention to their legal, financial, and organizational feasibility. (Schraven et al., 2022).

Although the project was initially developed with an IAAS framework in mind, it ultimately did not proceed under this model. Nonetheless, the circular solution of re-galvanizing guide rails was implemented. A significant challenge arose during the business case development, as client and contractor could not agree on the residual value of the re-galvanized rails, since the process restored them to near-original quality, their remaining value was disputed. Moreover, the re-galvanizing approach required the rails to be removed preventively, before the end of their technical lifespan, which in turn demanded additional inspections and planning from the contractor, leading to increased costs. The province deemed these extra costs too high for the limited project scope and decided not to pursue the IAAS model, although it did proceed with the re-galvanization method as a more sustainable replacement strategy.



Despite these hurdles, the province saw potential in the approach if applied on a larger scale. They indicated that a circular model could become viable if contractors operated across a broader area and managed preventive maintenance and reuse of rails within that network, creating a closed-loop system.

## 4.9 Sustainable Measures in Product Service Systems

To evaluate the extent to which sustainability was embedded in the pilot projects, the FHMs will be assessed based on the sustainable measures that were implemented. The FHMs for the Circular Road 2.0 projects are shown above in this chapter. For the Circular Road 1.0 projects, the original FHMs developed by Schraven et al. (2022) are provided in Appendix A: Functional Hierarchy Models from Schraven et al., and the reassessed versions, incorporating broader sustainability criteria, are presented in Appendix B: New Functional Hierarchy Models adjusted for sustainable measures.

While the original FHMs focused primarily on circularity, this study expanded the evaluation framework to include a wider spectrum of sustainability measures. This was achieved using the Environmental Value Drivers for PSS as outlined by Saccani et al. (2024), supplemented with an additional value driver, reduction of the negative impact on biodiversity, based on Opoku (2019). These environmental value drivers, listed in Table 4, served as the analytical framework for identifying which elements within each FHM could be considered sustainable measures. The updated FHMs used for this sustainability assessment are provided in Appendix B: New Functional Hierarchy Models adjusted for sustainable measures.

*Table 4: Overview of the environmental value drivers used to find sustainable measures in the FHM's*

| Environmental value driver | Description | Source |
|---|---|---|
| **Resource efficiency** | This focuses on maximizing the benefits gained from products or services while minimizing the environmental impact across their lifecycle. In a PSS context, this includes optimizing operations through services like regular maintenance or energy consumption management to reduce the amount of material and energy required during the use phase. | Saccani et al. (2024) |
| **Lifetime extension** | Extending the useful life of a product delays the need for replacement and reduces the consumption of new materials. This can be achieved through regular servicing, design improvements, or by maintaining ownership of the product, allowing the provider to ensure durability and longevity. | Saccani et al. (2024) |
| **Intensified product usage** | This aims to make better use of existing assets by increasing their usage time or capacity. Sharing models, for instance, allow multiple users to benefit from one product, lowering the total number of products needed and accelerating the turnover to newer, more efficient models. | Saccani et al. (2024) |
| **Increased/Improved recycling and reuse** | By reusing products or components and ensuring materials are recycled effectively, fewer new resources are required. PSS models that involve product take-back schemes or retain ownership over the product make it easier to recover and reprocess items at the end of use. | Saccani et al. (2024) |
| **Product system substitution** | When services replace traditional products altogether, such as using shared transport instead of private cars, it leads to a net reduction in resource use. These shifts are enabled by new technologies, business models, and economies of scale that provide sustainable alternatives. | Saccani et al. (2024) |
| **Dematerialization and transparency** | Dematerialization involves reducing the amount of physical material needed through services that deliver functionality rather than ownership. Transparency is supported by digital tools that track a product's condition, use, and maintenance history, enabling more precise and sustainable decisions throughout its lifecycle. | Saccani et al. (2024) |
| **Reduction of pollution and/or use of hazardous/toxic materials** | This driver involves minimizing harmful emissions and hazardous substances through environmentally friendly design, cleaner production methods, and sustainable material choices. It can also be achieved by redesigning products and systems to enable pooling or shared usage, reducing the total number of polluting units in operation. | Saccani et al. (2024) |
| **Reduction of the negative impact on biodiversity** | This value driver focuses on minimizing harm to ecosystems and wildlife throughout a product's lifecycle. | Opoku (2019) |

| | |
|---|---|
| | Through thoughtful design, such as reduced light pollution, managing green spaces that support local plants and fauna, and reduced noise pollution, PSS can help maintain ecological balance. |

Table 5 provides an overview of the identified sustainability measures across the seven pilot projects for which a FHM was available. The temporary road at Arena project is left out of this analysis as no FHM was made by Schraven et al. (2022) and no FHM could be made for this research. Each sustainability measure was classified according to its position within the FHM's three hierarchical levels: the demand level (DL), functional level (FL), and structural level (SL). To reflect the layered nature of these levels, the table differentiates between sub-levels (e.g., DL1, FL2, FL3), which denote the layer of the element within each hierarchical tier. This granularity offers insight into whether sustainability was embedded more at the strategic (demand) level, the operational (functional) level, or the technical (structural) level.

It should be noted that the FHMs for the Nieuwland and Noorderkroon projects are not yet finalised, as these projects are still in the design phase. The FHM for Nieuwland was developed based on input from the contractor side during the market survey, rather than from the actual contractor, who has not yet been selected. Consequently, the sustainability measures shown for these two projects are indicative and not definitive. They are included to provide a complete overview and to support comparison across all pilot cases.

*Table 5: Number of sustainable measures in the FHM per pilot.*
*DL = Demand level, FL = Functional level and SL = Structural level*

| Project | DL1 | DL2 | FL1 | FL2 | FL3 | SL1 | SL2 |
|---|---|---|---|---|---|---|---|
| **Nieuwland Public Lighting** | 1 | 0 | 3 | 2 | 0 | 4 | 0 |
| **Noorderkroon Residential Street Reconstruction** | 2 | 2 | 4 | 3 | 0 | 3 | 0 |
| **Rijkswaterstaat A6** | 1 | 0 | 1 | 3 | 0 | 4 | 1 |
| **Replacement of Bridge Decks** | 1 | 0 | 4 | 6 | 4 | 4 | 0 |
| **Reconstruction of Dr. J.P. Heijerlaan** | 1 | 1 | 3 | 5 | 1 | 3 | 0 |
| **Sustainable Road Lighting** | 3 | 0 | 6 | 0 | 2 | 4 | 3 |
| **Sustainable Guiderails** | 2 | 0 | 2 | 6 | 0 | 4 | 0 |

## Chapter Five: The Payment Structure

The choice of payment mechanism plays a critical role in influencing contractor behaviour and, by extension, the overall outcomes of infrastructure projects. As outlined in Chapter 2.2, Van Ostaeyen et al. (2013) distinguish four primary revenue mechanisms: input-based, availability-based, usage-based, and performance-based. The performance-based model can be further differentiated into three subcategories: solution-oriented, effect-oriented, and demand fulfilment-oriented, each defined by the level of abstraction at which performance is measured. These revenue structures are closely linked to the FHM, reflecting how value delivery and measurement are aligned within PSS, as illustrated in Figure 2.

This chapter examines the revenue models implemented across the eight pilot projects of The Circular Road program. It analyses the type of revenue mechanism applied in each case and evaluates which revenue model would be most appropriate from a functional hierarchy perspective, based on the theoretical framework developed by Van Ostaeyen et al. (2013). In addition, this chapter explores the relationship between the applied and theoretical revenue models and sustainability outcomes.

### 5.1 Payment Structure for Nieuwland Public Lighting – Amersfoort

#### 5.1.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM presented in Figure 5, it is possible to identify the most theoretically appropriate revenue mechanism for the Nieuwland public lighting project, drawing on the framework of Van Ostaeyen et al. (2013). The FHM reveals that the municipality of Amersfoort, as the client, defined clear customer demands as well as specific desired functional outcomes, particularly in relation to sustainability, light quality, and aesthetic criteria. In several instances, the municipality also provided functional solutions, such as digital maintenance platforms and specific dynamic lighting systems.



This structured and prescriptive approach limits the contractor's autonomy in determining how best to achieve these outcomes. Additionally, two technical requirements were set based on existing municipal regulations, which further constrain the contractor's freedom to innovate at the structural level.

According to Van Ostaeyen et al.'s (2013) typology, this positioning, where the client defines the functions and proposes some of the solutions, while only a limited degree of freedom is left to the contractor, aligns most closely with an availability-based revenue mechanism. In this model, the contractor is compensated for ensuring that the system or asset remains continuously available for use, regardless of how often or how intensively it is used. Performance indicators typically focus on uptime, reliability, or operational readiness rather than broader environmental impacts or usage-based outcomes. This fits with the prescriptive nature of the project, where the client retains substantial control over design and performance specifications but relies on the contractor to guarantee that the system functions consistently throughout its contracted availability period.

#### 5.1.2 Payment Structure in Practice

In the Nieuwland public lighting project, the potential application of a PSS model was explored. Although the model was ultimately deemed unsuitable for this specific case, the municipality initially envisioned a payment structure aligned with the AAS model. Under this approach, compensation would have been provided periodically over a five-year contract, with performance incentives linked to key sustainability indicators such as energy consumption, $CO_2$ emissions, and raw material use. This proposed structure corresponds to an effect-oriented performance-based revenue mechanism, where payment is tied to measurable environmental outcomes.

Despite these intentions, the municipality concluded that the AAS model offered no added value in this context, primarily because all lighting would be replaced at once. Consequently, the project will proceed under a traditional procurement approach, with a one-time payment and sustainability integrated into the tender's award criteria.

## 5.2 Payment Structure for the Noorderkroon Residential Street Reconstruction – Veenendaal

### 5.2.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM presented in Figure 7, the most fitting theoretical revenue mechanism for the Noorderkroon project can be assessed using the framework proposed by Van Ostaeyen et al. (2013). The FHM illustrates that the municipality of Veenendaal, as the client, has not only defined a comprehensive set of functional outcomes, particularly related to sustainability, greening, and the separation of waste- and rainwater, but has also specified several functional solutions, such as low life cycle cost, increased surface water, and a goal of 10% less paving.

In addition to these functional solutions, the municipality has also introduced a number of structural-level specifications, including specific technical standards for the road surface (e.g., load class E600) and design principles derived from their own urban policies. This level of prescription limits the contractor's design freedom and narrows the scope for innovation in achieving the desired outcomes.

Given the limited flexibility in defining both the solution and the outcome, this setup most closely aligns with an availability-based revenue mechanism as described by Van Ostaeyen et al. (2013). In such a mechanism, the contractor is primarily compensated for ensuring the continuous availability and usability of the infrastructure, rather than being rewarded for specific performance metrics or environmental impacts. In this case, the contractor would be responsible for maintaining the infrastructure in line with agreed quality and availability standards, potentially with penalties or deductions for unplanned closures or service interruptions. This aligns with the municipality's interest in minimizing disruptions for the inhabitants and ensuring long-term functionality, while retaining substantial control over the technical and functional direction of the project.



### 5.2.2 Payment Structure in Practice

The Noorderkroon project is still in its preparatory phase, and the precise structure of the payment mechanism has not yet been finalized. What has been established is that the construction and delivery phase will be compensated separately from the maintenance phase. Whether the contractor will also be awarded the maintenance contract remains uncertain. Since the area covered is relatively small, integrating it into the existing municipal maintenance framework may prove more efficient and cost-effective. Should the maintenance be assigned to the same contractor, it is expected to be contracted through a performance-based contract.

At present, there are no formalized financial incentives specifically linked to sustainability, although the municipality has expressed a strong ambition for the project to be delivered as sustainably as possible. A bonus-malus system is under consideration to further encourage performance, but its implementation has not yet been confirmed.

## 5.3 Payment Structure for Rijkswaterstaat A6 – Almere

### 5.3.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM for the A6 project (Figure 9), the most theoretically appropriate revenue mechanism, as described by Van Ostaeyen et al. (2013), appears to be the effect-oriented performance-based model. The FHM illustrates that a significant portion of the functional elements in the project were defined collaboratively between the client, RWS, and the contractor. This reflects the nature of the DBFM contract used for the project, in which the contractor is granted broad responsibility for delivering outcomes within a defined framework.

This framework includes fixed technical constraints, such as legal obligations for road safety features (e.g. road signs and guardrails) and quality benchmarks like the reference maintenance strategy and compliance with national road design standards. However, within these boundaries, the contractor retained considerable freedom to determine how to meet performance requirements. This is particularly evident in the project's approach to sustainability, where clear environmental objectives have been defined together (e.g. reduced $CO_2$ emissions, and low MKI) but it is left up to the contractor to decide how to achieve these outcomes through material choices, processes, and innovations.

According to Van Ostaeyen et al. (2013) model, this corresponds to an effect-oriented performance-based revenue mechanism. In this type of model, the contractor is compensated based on achieving predefined, objective, environment-centric performance indicators, such as reductions in environmental impact or lifecycle emissions (Van Ostaeyen et al., 2013). These indicators are formulated independently of the solution, meaning that the contractor has the flexibility to design and implement systems as long as the intended environmental outcomes are met.



### 5.3.2 Payment Structure in Practice

The Rijkswaterstaat A6 project was procured under a DBFM contract, a model that aligns with the principles of a PSS. The financing was arranged through private banks, and the project is currently in its maintenance phase, which will continue until 2039. The payment structure follows an availability-based model, where quarterly payments are made contingent on the infrastructure meeting predefined availability criteria. For instance, if elements such as lighting systems fail and compromise road safety, this is interpreted as a reduction in availability, resulting in deductions from the contractor's payment. These availability criteria are closely tied to a set of quality requirements.

No additional financial incentives for sustainability were introduced within this project, as the applied sustainability measures, such as reduced $CO_2$ emissions, also generated cost savings for the contractor. The integration of a residual value component into the financial model was explored but ultimately deemed infeasible due to the complexity of reliably predicting the extended lifespan of road components. As a result, residual value was not factored into the compensation structure.

## 5.4 Payment Structure for the Replacement of Bridge Decks – Amersfoort

### 5.4.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM in Appendix A: 9, which was developed by Schraven et al. (2022) for the bridge deck project in Amersfoort, the most theoretically appropriate revenue mechanism can be assessed using the framework of Van Ostaeyen et al. (2013). The overarching objective of this project is to deliver a bridge that is both circular and functional. The model shows that the municipality of Amersfoort, acting as the client, defined a comprehensive set of customer demands across safety, availability, user comfort, and sustainability dimensions. These demands were then elaborated through clearly specified functional effects, such as reducing noise pollution,  improving material quality, and ensuring safe separation between users.

The model also reveals that several functional solutions were determined by the client. For example, the municipality prescribed measures such as reducing the use of raw materials, incorporating bevelled profiles, and enabling the reuse of demounted materials. This reflects a relatively directive approach, which reduces the contractor's freedom to independently define how to meet the functional outcomes. Nevertheless, the contractor contributed as well, particularly with regard to functional solutions, by proposing elements such as efficient handling of noise complaints and the use of sustainable materials. Most technical specifications remain open to the contractor, with the exception of those governed by established regulations, such as NEN, CROW, and the HIOR, which introduces a degree of flexibility in selecting structural solutions.

Given this configuration, where the client defines the majority of functional requirements and some of the means to achieve them, but still leaves room for the contractor to propose certain solutions, the most appropriate revenue mechanism from a theoretical perspective is the performance-based, solution-oriented model. According to Van Ostaeyen et al. (2013), a solution-oriented performance-based mechanism links revenue to functional performance indicators that describe the performance of the solution itself, such as structural integrity or noise absorption, rather than to broader environmental impacts or user satisfaction.

This mechanism fits the bridge deck project well, as the revenue would be tied to how well the implemented solutions (e.g. renovated wooden planks, noise-reducing surfaces) perform in delivering the expected technical and functional outcomes. This reinforces the municipality's focus on maintaining control over key sustainability and safety parameters, while allowing some flexibility in how the contractor meets these within the defined framework.



### 5.4.2 Payment Structure in Practice

The bridge deck replacement project in Amersfoort was fully executed under an AAS model. In this arrangement, Dura Vermeer made the initial investment and receives compensation from the municipality through an availability-based revenue model. This compensation structure covers both the upfront investment and the required maintenance over the contract period. The model incorporates a bonus-malus system linked to circular performance and the MKI, thereby providing targeted incentives for sustainability. The contract duration is set at two years, after which a valuation will be conducted, and a residual value transfer will take place. This residual value will be determined based on the projected maintenance budget over the full expected lifespan of the assets.

## 5.5 Payment Structure for the Reconstruction of Dr. J.P. Heijerlaan – Amersfoort

### 5.5.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM shown in Appendix A: 11.22, developed by Schraven et al. (2022) for the Dr. J.P. Heijerlaan project in Amersfoort, the most appropriate revenue mechanism can be theoretically determined using the framework of Van Ostaeyen et al. (2013). The FHM clearly shows that the municipality of Amersfoort, acting as the client, defined all the customer demands across various domains, including safety, road availability, and sustainability. These demand level objectives are further specified through detailed functional effects, such as ensuring continuous road maintenance, reducing ecological impact, and fostering circularity by reusing materials at end-of-life.

The model also illustrates that the municipality went beyond defining functional goals and took an active role in prescribing the means to achieve them. Many of the functional solutions, such as the selection of sustainable materials, integration of biodiversity considerations, and the need to follow national guidelines, were initiated by the client. Additionally, technical specifications were provided at the structural level, including requirements around the design of the road, and even aesthetic guidelines. These prescriptions, combined with national standards such as NEN and CROW, leave little open for contractor interpretation, and thus limit opportunities for technical or functional innovation by the executing party, Dura Vermeer.

Given this configuration, where the client has maintained full control over the demands and has pre-defined most of the functional and technical implementation strategies, the most suitable revenue mechanism from a theoretical standpoint is the availability-based model. According to Van Ostaeyen et al. (2013), availability-based mechanisms are appropriate in contexts where the contractor's primary responsibility is to ensure that the asset, here, the road, remains functional and accessible over time. In such models, compensation is typically tied to asset availability, with penalties or deductions applied in cases of non-compliance or service interruption.

This fits the Dr. J.P. Heijerlaan project well, where the road had to remain available according to strict specifications, and the contractor was incentivised through a bonus-malus system linked to MKI performance. The client's directive approach, combined with limited contractor autonomy, aligns clearly with a revenue mechanism that compensates for service uptime rather than for functional or environmental outcomes. This structure ensures compliance with the municipality's sustainability and performance ambitions, while placing the risk and responsibility for availability on the contractor.

### 5.5.2 Payment Structure in Practice



The reconstruction of the Dr. J.P. Heijerlaan in Amersfoort was also carried out under an AAS model. As in the bridge deck project, Dura Vermeer covered the initial investment and is compensated through periodic payments. The contract spans two years, concluding at the beginning of the following year. The maintenance activities are covered through a quarterly availability-based service fee. Compensation for the design and realization costs, however, was paid separately and not included in the service fee.

The availability model is structured around road accessibility: a malus is applied if road closures exceed the number of days agreed upon in the contract. To promote sustainability, a bonus-malus system based on the MKI was incorporated. The MKI performance is measured against a reference design to incentivize the use of more sustainable materials and methods. While no further formal incentives for sustainability were embedded in the contract, the municipality emphasized a strong preference for delivering a highly sustainable solution.

During the design phase, conducted through early contractor involvement, Dura Vermeer developed multiple alternatives, and the municipality ultimately selected the most sustainable option. It was noted by several participants that the very discussion around service fees and lifecycle planning significantly contributed to sustainable outcomes. By jointly reviewing lifecycle costs, an approach that is not yet standard practice, both parties gained insights into how design choices impact long-term maintenance costs and service compensation, thereby integrating sustainability more effectively into the decision-making process.

## 5.6 Payment Structure for the Temporary Road at Arena – Amsterdam

### 5.6.1 Payment Structure Based on the Functional Hierarchy Model

No FHM model was developed by Schraven et al. (2022), as the project was still in the early stages of the design phase at the time of their research. Key components of the IAAS framework, particularly the circular and financial aspects, had not yet been finalised, making it premature to translate the project into a fully formed FHM.

Similarly, an FHM has not been constructed for this project as part of this study. Although relevant insights were obtained through interviews with one stakeholder group, a complete and balanced model requires input from both client and contractor perspectives. Since a full understanding of how customer demands and functional requirements were defined could not be established during the research period, it was not feasible to develop a comprehensive FHM for this case.

### 5.6.2 Payment Structure in Practice

The temporary road project near the Johan Cruijff Arena in Amsterdam was executed under an existing framework agreement. Within this framework, Dura Vermeer was contracted to carry out minor road works in a designated area of the city. The project followed a traditional procurement model, with a one-time agreed-upon price rather than a service-based payment structure. Although the contract included maintenance obligations, it was anticipated that little to no maintenance would be required during the two-year contract period. When the asphalt later began to show signs of tearing, these issues were addressed under the warranty rather than classified as part of regular maintenance.

Initially, a service-based contract structure was developed for this project; however, it was ultimately not implemented. The decision stemmed from the municipality's assessment that the intended technical and sustainability goals could also be achieved through a traditional contract. Additionally, the municipality of Amsterdam preferred to finance the project themselves, citing their access to lower interest rates compared to private contractors, thereby making public financing more cost-effective. While there were no formal sustainability incentives embedded in the payment structure, the municipality explicitly stated its ambition to make the project as sustainable and innovative as possible, encouraging the use of recycled materials and innovative construction practices.



## 5.7 Payment Structure for Sustainable Road Lighting – North Brabant

### 5.7.1 Payment Structure Based on the Functional Hierarchy Model

The overall objective of the FHM in Appendix A: 11.33, developed by Schraven et al. (2022) for the road lighting project in North Brabant, was to deliver an effective lighting service. At the demand level, the Province of North Brabant, as the client, defined nearly all of the customer demands. These include ensuring continuous service, maintaining traffic safety, improving energy efficiency through digital solutions, energy savings, ensuring clarity and improving environmental friendliness.

This top-down structuring continues into the functional level, where the client determined most of the desired outcomes, such as ensuring the right light quality, accident supervision, reducing $CO_2$ emissions, and reduction of light pollution. Notably, several functions, particularly around incident monitoring, dynamic dimming, and the availability of light, were defined collaboratively by both client and contractor, signalling an intent for co-creation and shared accountability in certain performance areas.

At the functional solution level, a shift in control begins to emerge. The contractor contributed significantly here, monitoring disruptions and proposing modular lighting system designs. While the client still specified certain performance outcomes, such as the target of 50% $CO_2$ reduction, the contractor's influence became more prominent in suggesting how to technically realise these effects.

This contractor-led contribution is even more pronounced at the structural level, where nearly all technical requirements and design specifications are determined by the contractor. These include the implementation of system monitoring tools, recycling of components, and the integration of centralised software systems. The only exception is the client-imposed requirement that systems adhere to provincial technical standards.

Taken together, this distribution of responsibilities reflects a revenue model in which the contractor is tasked with developing and delivering a highly functional and technically advanced solution within a framework of predefined client expectations. The client sets the performance goals and co-defines key effects but relies on the contractor to determine the best structural and operational approach to meet those goals. This balance aligns most closely with a performance-based, effect-oriented revenue mechanism, according to Van Ostaeyen et al.'s (2013) typology.

In an effect-oriented revenue model, payments are tied to how well the system performs in its operational context, not just whether it functions, but whether it achieves specific, measurable environmental or societal outcomes. In this case, performance indicators such as $CO_2$ reduction, energy efficiency, and continuous light availability are key targets. The contractor is incentivised to achieve these broader system effects rather than just delivering and maintaining a physical product.

The model captures a shared ambition for innovation and sustainability while preserving the client's strategic oversight. It enables the contractor to operationalise innovative solutions that meet the desired performance effects and aligns financial incentives with functional outcomes, an essential characteristic of effect-oriented contracts in PSS models.

### 5.7.2 Payment Structure in Practice



This project was implemented under an AAS model, though the initial realization phase of the public lighting had already been completed through a traditional contract. Subsequently, adjustments were made to the existing infrastructure to enable dimmable lighting, and this transition marked the formal adoption of the AAS model. The updated contract included both ownership and maintenance of the lighting system over a period of eight years, with the contractors leasing the lighting infrastructure to the province of North Brabant.

The financial structure of the contract was based on an effect-oriented performance based model. The contractors calculated the service fee by translating the total investment and maintenance costs and distributing them across the entire contract period. Payment was linked to several performance indicators, with the primary condition being the availability of functional lighting. Additional metrics included error response time, energy consumption, $CO_2$ emissions, and the use of sustainable materials. If performance requirements were not met, a payment freeze would be triggered; however, this situation has not occurred during the contract term.

As a result of the project, a 55% reduction in energy consumption was achieved. Beyond energy savings, the dimmable lighting system contributed positively to biodiversity and extended the lifespan of the luminaires by an estimated five to ten years. The project thus demonstrates how performance-based AAS models can align financial and sustainability objectives in public infrastructure.

## 5.8 Payment Structure for the Sustainable Guiderails – North Holland

### 5.8.1 Payment Structure Based on the Functional Hierarchy Model

Based on the FHM in Appendix A: 0, developed by Schraven et al. (2022) for the guiderail pilot project in North Holland, the overarching objective of the project was to promote greater circularity in the use and management of guiderails, while also ensuring safety, continuous maintenance, and a reduced ecological footprint. Within this framework, the province of North Holland, acting as the client, defined all of the core customer demands at the demand level.

At the functional level, the client also specified the majority of the desired effects, such as the use of circular materials and the continuous availability of the road. Several functional solutions were likewise determined by the client, including requirements for a lower MKI, reduced material usage, the preservation of biodiversity, and adherence to safety strategies based on national guidelines. However, at the structural level, more space was left for the contractor to innovate. Here, the contractor contributed specific technical solutions such as the use of regalvanised guiderail components, material repairs, and the implementation of material passports.

This balance between a client-defined functional framework and contractor-led technical implementation is characteristic of a performance-based, solution-oriented revenue mechanism. According to Van Ostaeyen et al. (2013), this mechanism ties revenue to performance indicators that measure the effectiveness of the contractor's solution itself, such as the durability, reusability, or residual value of the renovated guiderails, rather than broader system or environmental effects. It allows for targeted innovation by the contractor while still operating within clearly defined performance expectations set by the client.

In this project, the emphasis on contractor-developed solutions like regalvanising guiderails and calculating residual value aligns well with the logic of solution-oriented compensation. The client retains control over the desired outcomes (e.g. safety and circularity), while the contractor is incentivised to develop and deliver high-performing solutions that meet those expectations. This combination makes the solution-oriented performance-based model a theoretically fitting revenue approach for this type of PSS implementation.



### 5.8.2 Payment Structure in Practice

In this project, Dura Vermeer was already operating under an existing framework agreement with the province of North Holland. Within the scope of this agreement, both parties explored the feasibility of applying an AAS model to the renovation of guiderails. The client retained the option to withdraw from this contract form should the model, after two years of research and development, prove to offer insufficient added value. Ultimately, while the AAS model was developed in detail, the project proceeded under a traditional contract structure. The guiderails were renovated using the proposed circular solution, re-galvanising existing guiderails, but this was executed through a one-time payment rather than a service-based arrangement. Following the replacement, the remaining contractual period was only six months, during which Dura Vermeer remained responsible for maintenance, though not under a formal AAS framework.

Despite the initial enthusiasm for a circular contracting approach, the province ultimately decided against implementing an AAS model. One key reason was the difficulty in justifying the higher cost associated with the service-based model, especially when the same sustainable outcome could be achieved under a traditional contract. In addition, determining the residual value of the guiderails proved to be complex and contentious. Given the long lifespan of guiderails (approximately 25 years) and their relatively low maintenance needs, typically limited to post-collision replacement, the asset was not considered well-suited to an AAS structure. These factors led the province to conclude that, in this specific case, a traditional procurement approach was more appropriate.

## 5.9 Comparison Between FHM-Based Theoretical Revenue Model and Practical Revenue Model

Table 6 compares the revenue models implemented in practice across the eight Circular Road pilot projects with the theoretically appropriate mechanisms, as determined using the FHM and the revenue typology by Van Ostaeyen et al. (2013).

*Table 6: Comparison of practical and theoretical payment mechanism applied the pilot projects*

| Project | Practice | Theory |
|---|---|---|
| **Nieuwland Public Lighting** | Input-based | Availability-based |
| **Noorderkroon Residential Street Reconstruction** | Undetermined | Availability-based |
| **Rijkswaterstaat A6** | Availability-based | Effect-oriented performance based |
| **Replacement of Bridge Decks** | Availability-based | Solution-oriented performance based |
| **Reconstruction of Dr. J.P. Heijerlaan** | Availability-based | Availability-based |
| **Temporary Road at Arena** | Input-based | - |
| **Sustainable Road Lighting** | Effect-oriented performance based | Effect-oriented performance based |
| **Sustainable Guiderails** | Input-based | Solution-oriented performance based |



This comparison is particularly interesting, as it highlights the divergence between theoretical best practice and what was actually applied in the field. The FHM analysis, combined with the revenue model typology, suggests that many projects would theoretically benefit from adopting more performance-based approaches (solution-oriented or effect-oriented), as these models are better aligned with the intended project dynamics.

However, in practice, most projects defaulted to more traditional models such as input-based or availability-based mechanisms. These traditional mechanisms are often easier to implement and less risky from a contractual perspective but tend to offer fewer direct incentives for sustainability. For instance, input-based contracts focus on delivering predefined activities or materials, without linking compensation to long-term performance or environmental outcomes. On the other hand, performance-based models can be structured to stimulate sustainability more directly. These models typically include bonus-malus systems, where the contractor receives a financial bonus for exceeding predefined sustainability targets or incurs penalties if targets are not met. These mechanisms create a financial incentive to innovate and invest in sustainable practices beyond the minimum requirements.

The consistent preference for more conventional models in practice, despite theoretical recommendations, suggests that stakeholders may face challenges in translating performance-based designs into workable contracts. This gap between theory and practice raises important questions about the barriers that prevent the adoption of more advanced PSS models, even in projects explicitly aimed at driving circularity and sustainability. Understanding these gaps can provide valuable insights for improving future project design and contract structuring within The Circular Road program and similar initiatives. Chapter Six: Barriers to Implementing Product Service Systems explores the barriers to implementing PSS.

## 5.10 Sustainable Measures and the Payment Model Relationship

In order to enable meaningful comparison across projects, the number of sustainable elements was converted into a percentage of the overall FHM. This was done by dividing the total number of sustainability-aligned elements by the total number of elements in each project's FHM. This method offers a normalized metric for assessing the relative integration of sustainability, irrespective of differences in project size or complexity. Only The Circular Road 1.0 projects and the Rijkswaterstaat A6 case were included in this analysis, as the other Circular Road 2.0 projects are still in their design phases and lack complete information on concrete sustainability interventions. Furthermore, the temporary road at Arena case was also excluded as no FHM was, or could be made for this project.

Figure 10 visualizes these percentages in relation to the revenue model used in practice for each project. The x-axis represents the type of revenue mechanism, while the y-axis reflects the percentage of sustainability measures identified. Each project is plotted as a data point labelled with its project name.

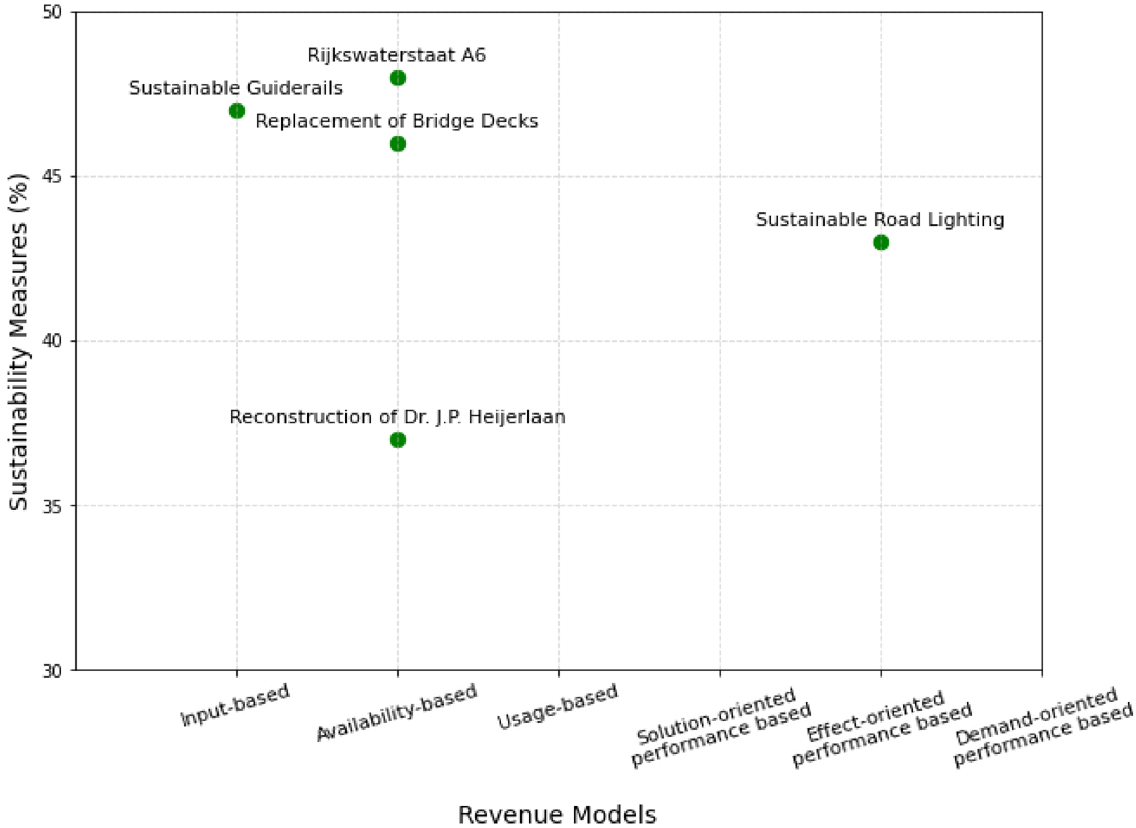


*Figure 10: Graph of the percentage of sustainability measures by revenue model per project*

The graph reveals that sustainability can be achieved under various types of revenue models. For instance, the Sustainable Guiderails project, which followed a traditional input-based payment model, achieved one of the highest sustainability percentages. Similarly, projects using availability-based contracts, such as the Rijkswaterstaat A6 and the Replacement of Bridge Decks, also demonstrated strong sustainability integration. These findings suggest that even conventional payment structures do not inherently prevent the implementation of sustainable measures, particularly when sustainability is prioritized by project stakeholders.

At the same time, the Sustainable Road Lighting project, which employed an effect-oriented performance-based revenue mechanism, also achieved a high percentage of sustainability elements. This supports the theoretical assumption that more advanced performance-based models, particularly those focused on environmental outcomes, can incentivize or support sustainability through contractual alignment.

However, the overall pattern in the graph does not indicate a consistent or linear relationship between revenue model type and the percentage of sustainable measures. This lack of a clear trend suggests that while payment mechanisms can influence the sustainability performance of a project, other contextual factors, such as contractor initiative, client ambition, and project scope, play equally important roles. As such, revenue models alone may not determine sustainability outcomes but rather act as one of several enabling or constraining variables in a broader ecosystem of decisions.

When examining the theoretical revenue models, those that should have been implemented based on the FHM analysis, a potential relationship between the percentage of sustainability measures and the type of revenue model begins to emerge. Figure 11 illustrates the relationship between the theoretical revenue model and the percentage of sustainability measures across the analysed projects.

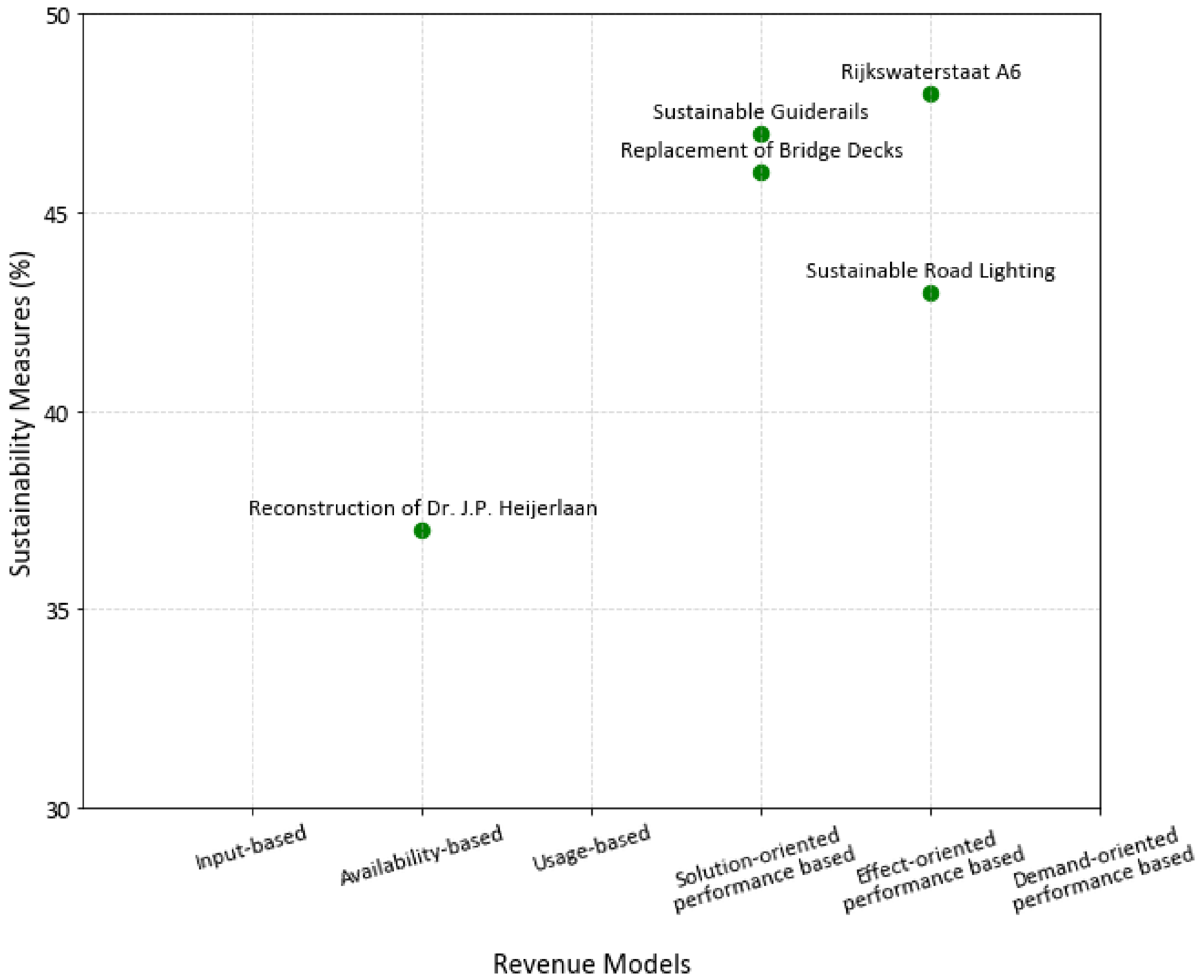


*Figure 11: Graph of the percentage of sustainability measures by theoretical revenue model per project*

The Reconstruction of Dr. J.P. Heijerlaan project, which has the lowest percentage of sustainability measures, corresponds to the least performance-oriented revenue model in theory (availability-based). This observation aligns with the assumption that more performance-based revenue models may foster higher sustainability outcomes.

In contrast, the projects with solution-oriented and effect-oriented performance-based revenue models, such as the sustainable road lighting and replacement of bridge decks, exhibit higher percentages of sustainability measures. This supports the notion that performance-oriented models can incentivise the integration of sustainability, as these models typically give contractors more freedom to innovate and optimise outcomes.

However, the results are not entirely linear. The sustainable road lighting project, despite having an effect-oriented performance-based model, shows a slightly lower sustainability percentage than some of the solution-oriented projects. This suggests that simply adopting a more advanced revenue model does not automatically guarantee higher sustainability; other factors, such as project context, client ambition, and contractor engagement, also play a significant role.

Moreover, it is important to note that this analysis is based on theoretical models rather than models that were applied in practice. Therefore, no definitive conclusion can be drawn that a more performance-based revenue model inherently leads to greater sustainability. What can be observed is that in projects where the contractor had more flexibility and freedom to propose innovative solutions, this tended to result in a higher integration of sustainability measures.

### 5.10.1 Stakeholder Perceptions of the Revenue Model's Role in Driving Sustainability

Insights from the interviews revealed diverse perspectives on whether the revenue model itself actively contributes to achieving sustainability in PSS projects. While not every participant felt certain, the dominant view across both client and contractor sides was that the structure of payments alone does not inherently drive sustainability outcomes. Rather, it is the mindset and collaborative approach fostered within a PSS framework that helps embed sustainability into project delivery.

Several participants noted that because PSS models explicitly encourage longer-term thinking and lifecycle approaches, they naturally lead to practices such as implementing material passports or conducting life cycle cost calculations, measures that are often overlooked in conventional contracts. However, they emphasised that it was not the payment mechanism itself that drove these outcomes. Instead, the greater emphasis placed on sustainability within the project dialogue, and the open conversations between client and contractor around sustainable objectives, were the real catalysts for integrating these measures.



Some interviewees further suggested that the payment structure is largely detached from sustainability goals and is treated more as a financial mechanism agreed upon during contract negotiations, essentially, a pricing tool rather than a sustainability lever. Others observed that while more sustainable solutions often carry higher costs, periodic payments (typical in performance-based models) can help spread these costs over time and ease immediate financial impacts, although they do not necessarily lower total project costs.

Interestingly, many participants believed that similar sustainability outcomes could still be achieved under traditional contracts with conventional input-based payment structures, provided there is sufficient ambition and cooperation between the parties. In this view, the critical factor is not the form of payment but the shared commitment to sustainable delivery embedded in project culture and collaboration.

# Chapter Six: Barriers to Implementing Product Service Systems

While PSS present promising opportunities for fostering sustainability and innovation in the infrastructure sector, the implementation remains challenging. Both theory and practice highlight a range of barriers that can impede the successful adoption of PSS models in construction projects. These barriers span five key dimensions: financial, organisational, behavioural, regulatory, and contextual.

This chapter systematically explores the barriers encountered in The Circular Road pilot projects, offering practical insights into how they manifest during project implementation. First, the chapter presents the barriers observed in practice from the contractor's perspective, structured across five dimensions. This is followed by an analysis of the barriers experienced from the client's perspective. Finally, the chapter brings theory and practice together, all barriers identified through the pilot projects are compared with those documented in the academic literature. This comparative analysis provides a clear picture of which barriers are consistently recognised across both domains, and where new or underexplored challenges emerge in real-world infrastructure projects. By identifying these gaps and overlaps, this chapter helps inform future strategies to support more effective and scalable implementation of PSS in the infrastructure sector.

## 6.1 From the Contractor's Perspective

From the contractor's point of view, the implementation of PSS or AAS contracts presents a promising yet complex challenge. While these models offer potential for sustainability advancement long-term collaborations, and infrastructure innovation, contractors face a range of practical, financial, and structural obstacles that can limit their feasibility and attractiveness. These challenges are interconnected and encompass financial, organisational, behavioural, regulatory and contextual dimensions.



### 6.1.1 Financial Barriers

Financial concerns are among the most significant hurdles for contractors considering PSS implementation. Unlike municipalities, contractors usually face higher interest rates, making it more expensive for them to finance the initial investments required for asset delivery, long-term maintenance, and performance guarantees. This difference puts contractors at a disadvantage when developing viable business cases for AAS contracts.

Small and medium-sized enterprises (SMEs) face even greater difficulties. Limited access to financing, combined with a lack of experience with PSS contracts, raises the barrier to entry. Smaller firms may find it impossible to take on the high initial investment costs, effectively excluding them from participation in AAS tenders. As a result, such contract formats may unintentionally benefit larger, more capital-rich contractors, compromising inclusivity in public procurement.

Another major financial uncertainty lies in the calculation of residual value. Contractors often expect to recoup part of their investment through the value of the asset at the end of the contract period. However, determining the objective residual value of infrastructure assets, especially when they are refurbished or reused, is complex and uncertain. Disagreements frequently arise between clients and contractors about how to value assets, such as re-galvanized guiderails, particularly when their technical lifespan is extended. This lack of consensus poses a substantial risk to the contractor's return on investment.

Moreover, pricing the monthly or quarterly service fees under availability- or performance-based contracts is a considerable challenge. These fees must reflect long-term costs, risk buffers, and performance guarantees, all of which require careful forecasting. Due to the lack of historical data and precedents, contractors are frequently working in uncharted territory. Both sides find it difficult to build trust and come to a financial agreement in the absence of a transparent and trustworthy pricing structure.

The absence of open-ended budgets from public clients such as Rijkswaterstaat adds to this complexity. Although cost management is essential, strict financial restrictions might stifle creativity and the flexibility needed to modify the contract in response to new knowledge or evaluations of performance. For contractors, this creates a rigid financial framework that limits their ability to propose innovative or long-term sustainable solutions that may require initial adjustments or unforeseen expenditures. It also discourages adaptive management, as any deviation from the original scope may be rejected due to budgetary constraints. Lastly, in PSS pilots, contractors are frequently required to provide complete cost transparency. Although this promotes accountability, it can put contractors in a commercially vulnerable position.

### 6.1.2 Organisational Barriers

From an organisational standpoint, contractors must greatly increase their operational duties when adopting PSS or AAS contracts, frequently replicating procedures that are already in place within municipal institutions. Municipalities normally oversee resident communications, incident response, and maintenance reporting under conventional contracts. The contractor must establish whole new operational systems, including malfunction reporting services, stakeholder communication channels, and long-term asset monitoring procedures, when these duties are transferred to them via an AAS model. This parallel system becomes highly inefficient and overly costly for contractors managing only a small fraction of municipal infrastructure. In addition to reducing the model's effectiveness, this duplication of effort makes stakeholder coordination more difficult.



Another important consideration is the project's contractual and geographic scope. Only when the contractor oversees a sizable enough region to justify the extra expenditure and infrastructure, do AAS contracts become organisationally feasible. When contractors are tasked with managing fragmented or minor components of a municipality’s network, such as a single road segment or a small neighbourhood in a big district, the investment in long-term organisational capacity lacks scale and cannot be economically justified. A broader scope is necessary to ensure optimal resource allocation and long-term maintenance planning.

Furthermore, for these new models to be effective within a contractor's organisation, there must be a clear mandate from both the contracting authority and the executing firm. Since implementing an AAS contract often requires deviating from traditional procedures, project teams might not be able to innovate if they lack sufficient internal backing or decision-making authority. This lack of mandate frequently causes hesitancy or inaction, particularly when combined with unfamiliarity or discomfort with non-traditional contract models.

Another major organisational constraint arises when the infrastructure in question involves public safety. In such cases, municipalities and governments are ultimately held responsible for outcomes, regardless of the contractual arrangements. As a result, public clients tend to reduce risk exposure by maintaining control over design and performance requirements. This limits the contractor's capacity to use innovative concepts or optimise asset performance, however they can still be held responsible for performance and delivery, resulting in an imbalance of authority and responsibility.

Finally, the duration of the contract is essential to the organisation. Contractors need a long enough time horizon to justify the initial investment and operational changes. Short-term contracts, which are just a few years long, do not give the contractor enough time to recoup investments and fully reap the benefits of sustainability and efficiency measures. In such cases, traditional procurement approaches often remain more feasible.

Taken together, these organisational barriers reveal a mismatch between the operational demands of AAS models and the fragmented, risk-averse structure of current infrastructure management. For contractors to embrace these new approaches, there must be greater alignment between project scope, mandate, responsibility, and the ability to innovate. Without this, the burden placed on contractors may outweigh the potential benefits of PSS-based delivery models.

### 6.1.3 Behavioural Barriers

Adoption of AAS models is frequently hampered by deeply embedded behavioural resistance in the construction industry, in addition to organisational and financial barriers. The sector is known for its conservative culture, which is characterised by a general aversion to risk and a devotion to conventional methods. For many contractors, the transition from product delivery to long-term service supply signifies an entirely new approach in the design, implementation, and upkeep of infrastructure, in addition to a change in the terms of the contract.

Within a contractor's organisation, this resistance may appear on several levels. For instance, technicians and engineers might be more interested in the tangible components of a project and struggle to interact with long-term service objectives or abstract contract forms. Their knowledge is usually focused on construction rather than managing, which may restrict the internal support required for an AAS implementation to be successful.



At the project management level, limited knowledge and competence regarding PSS models can lead to hesitation or outright rejection of the concept. When decision-makers are unfamiliar with service-based contracts, they may underestimate its benefits or overestimate its risks, particularly if they fear that clients are unwilling to pay extra for sustainability. This perceived lack of client commitment can demotivate contractors from investing in circular and innovative solutions.

### 6.1.4 Regulatory Barriers

Another obstacle for contractors interested in PSS models is the regulatory environment. Currently, certain sustainable activities, such as the use of electric construction equipment, can be economically reimbursed through government programs or subsidies. Nevertheless, it is unclear how long these incentives will be available. If such practices become mandatory under new environmental regulations, they will no longer offer contractors a competitive advantage, potentially altering the cost-benefit calculation for adopting sustainable innovations. Sudden or unclear shifts in environmental standards, procurement rules, or data requirements can disrupt the contractors business case. Without early and transparent communication from public authorities about forthcoming changes, contractors are reluctant to commit to long-term service contracts that rely on assumptions about evolving legal requirements.

Client control over technical requirements is another significant obstacle. In many public infrastructure projects, the client based on their rules and regulations specifies the materials, designs, and performance standards in great detail. When these criteria are too rigid, this provides limited possibility for innovation, thereby negating the benefits of a service-based model. If the contractor is unable to make autonomous decisions about how to attain functional results, the incentive to innovate diminishes and the value proposition of AAS becomes limited.

### 6.1.5 Contextual Barriers

Some barriers to PSS implementation do not fall neatly into one category but arise from the contextual complexity of infrastructure projects. One such concern is project scale. Only when implemented on a large enough scale do many AAS concepts become operationally and economically feasible. The transaction costs of establishing a specialised service system, including staff, monitoring equipment, and reporting systems, are disproportionately high if a contractor is only in charge of maintaining a small asset or area. A standard contract is more manageable and cost-effective in these situations for both the client and the contractor.

A final barrier concerns the challenge of demonstrating the long-term sustainability and durability of proposed solutions. For contractors, this uncertainty complicates financial forecasting and risk management. For instance, when an asphalt type is expected to outperform conventional options by lasting three years longer, this projection is often based on theoretical models or laboratory tests rather than verified field data. As a result, the contractor must bear the risk that the material may not perform as expected in practice. For contractors, this uncertainty complicates financial forecasting and risk management. For instance, when an asphalt type is expected to outperform conventional options by lasting three years longer, this projection is often based on theoretical models or laboratory tests rather than verified field data. As a result, the contractor must bear the risk that the material may not perform as expected in practice. To mitigate this risk, they may choose to increase the service fee, which can be met with resistance from the client. This creates a contradiction between the desire to implement new, circular solutions and the financial risk that contractors are ready, or able, to accept, thereby limiting the implementation of promising but unproven techniques.

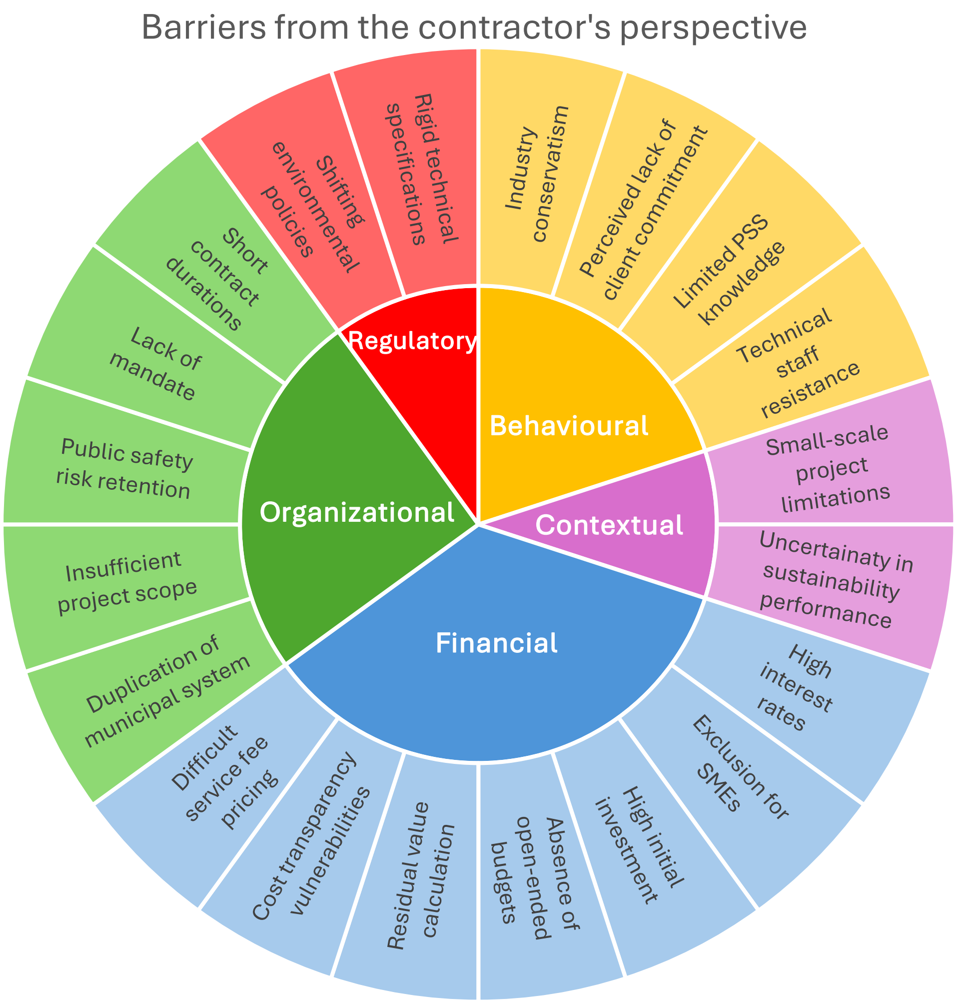


*Figure 12: Barriers from the contractor's perspective*

## 6.2 From the Client's Perspective

The application of PSS from the client's side, typically municipalities, provinces or public authorities, also presents a range of complex challenges. These barriers span financial, organisational, behavioural, regulatory, and contextual dimensions, often intertwining in practice and complicating the implementation of service-based models such as IAAS.

### 6.2.1 Financial Barriers

From a financial perspective, several barriers complicate the implementation of PSS for public clients. A major issue lies in understanding and structuring the economic model of such contracts. PSS involves long-term financial commitments, including monthly or quarterly service fees, which are more challenging to assess than traditional procurement, where prices are primarily upfront and straightforward. Public clients frequently struggle to understand what these fees cover, how they compare to traditional models over time, and what potential obligations may arise. Because of this complexity, it is challenging to determine whether PSS arrangements are more cost-effective.

One specific challenge is the difficulty of determining and agreeing on residual value. Since the long-term condition of an asset, such as lighting poles or guardrails, might vary substantially based on usage, maintenance, and refurbishment possibilities, it is difficult to determine how much value remains at the expiration of the contract period. The client may pay a disproportionately higher amount if a contractor is able to recondition an asset (for example, by regalvanising) and use it as if it were new, but the client anticipated a zero residual value in the financial model. This uncertainty directly affects the calculation of service fees and complicates negotiations between client and contractor.

The organisation of public maintenance presents another financial obstacle. Usually, municipalities hire one party to handle all of the upkeep for the entire area. When a PSS pilot project designates a small area for external management, such a small section of a district or a set of light poles, the municipality is essentially paying the PSS provider twice: once to its general maintenance contractor and once to the PSS provider. This cost duplication makes service-based contracts less appealing from an economic standpoint, particularly for small-scale operations.

In addition, municipalities benefit from significantly lower borrowing rates than private contractors. While PSS intends to redirect the investment burden from public to private players, the financial benefit of this shift is unclear given that the public sector may obtain financing at significantly cheaper interest rates. In such cases, traditional investment may remain more cost-effective, particularly when the project does not clearly benefit from private-sector innovation or performance incentives.

Another practical concern is the fragmentation of budgets across municipal departments. The capital expenditure (e.g. for installation of assets) and the operational expenditure (e.g. for maintenance) are often managed by different divisions. When a PSS contract results in higher upfront costs but lower lifecycle costs, the department responsible for the initial investment may reject it, despite long-term savings for the organisation as a whole. This lack of integrated financial decision-making presents a structural barrier to lifecycle thinking and value-based procurement.

Finally, municipalities operating within the pilot programs The Circular Road have encountered difficulties related to pricing and internal cost awareness. Due to pre-existing partnerships or contractors' direct involvement in the program's development, competitive tendering was not used in most projects, which left clients without benchmarks by which they could assess whether suggested costs were fair or cost-effective. This uncertainty was exacerbated by their lack of knowledge of internal expenditures, including long-term operating expenses, routine maintenance, and data management. It became especially difficult to assess the added value of PSS contracts in the absence of a defined benchmark for comparison. Additionally challenging were attempts to design sustainability incentives, including MKI bonuses. Following initial budget allocations, there is minimal opportunity to reward circular innovations due to the fixed and segmented nature of municipal budgets.

### 6.2.2 Organisational Barriers

Municipalities and government authorities encounter many organisational and procedural constraints that impede the implementation of PSS. The incompatibility of current financial administration systems with the long-term, recurring payment arrangements characteristic of service-based contracts is a significant obstacle. Municipalities often seek one-time project credits, whereas PSS models call for budgeting over long timeframes, even decades, necessitating a significant change in the procedures for financial planning and approval.

Municipalities frequently run internal systems for managing public assets, including maintenance services. Currently, the PSS contracts cover only a small sector of a district creates redundancy since a contractor gets paid to maintain a smaller, detached section while the current municipal team continues to handle the wider area. This raises costs without providing equivalent benefits since it leads to inefficiencies and duplication of effort. It also causes confusion among citizens, who continue to approach the municipality with complaints or difficulties, when responsibility has been transferred to the contractor.

Organisational readiness is further complicated by capacity limitations and internal communication. Project managers must persevere in persuading colleagues of the advantages of a new contract model while simultaneously reorganising long-standing protocols and systems. Explaining the idea of a PSS to colleagues can be difficult for project managers, especially in departments that are not familiar with the model or its implications. Because PSS is abstract, it might be hard to understand, which can cause hesitancy or miscommunication inside the municipality. Furthermore, the early phase of a PSS contract necessitates a substantial time and effort commitment in order to coordinate departments, create monitoring systems, and build new processes. However, the required capacity for this intensive start-up phase is not always available, especially in smaller municipalities or overburdened departments. Therefore, even in cases where there is a strategic interest in innovation or circularity, there may not be enough operational bandwidth to pursue it using a service-based approach.



Moreover, accountability remains a central concern. Even when maintenance is outsourced, the municipality retains legal and reputational responsibility for the public infrastructure. This raises critical questions about oversight: what information does the municipality need to retain in order to steer the project effectively, and how can it ensure that contractor performance aligns with internal standards? This dilemma frequently leads to the establishment of parallel oversight structures, where municipal teams continue to monitor and verify the contractor's work. Although this is required for transparency and compliance, it also means that governments continue to bear the responsibility and costs of contract management while outsourcing its execution, which compromises some of the efficiencies that a PSS contract aims to provide.

### 6.2.3 Behavioural Barriers

Behavioural opposition inside municipal and government entities adds another degree of difficulty to adopting PSS contracts. The cultural reluctance to give up control is a significant barrier. Municipalities are used to carefully specifying and managing outcomes, but a service-based approach asks them to stand back and give the contractor more freedom to produce the agreed-upon results. This change in responsibilities frequently causes unease, especially when governments question if contractors share their long-term public interest objectives or worry that contractors are driven primarily by financial gain.

Such mistrust can manifest in rigid tender requirements or overly prescriptive contracts. Some contractors indicated that there were sometimes few possibilities to offer creative suggestions, especially those that somewhat deviated from the original specifications. Since standards were viewed as non-negotiable, contractors' suggestions for alternate strategies with possible sustainability benefits were not usually introduced. This highlights a potential area for further dialogue in future projects, where exploring the value of such alternatives in a structured way could support shared sustainability objectives while respecting established requirements.

Clients also experienced difficulty abandoning established procurement processes. Creating and executing a PSS contract requires not only technical adjustments but also a major shift in perspective and internal procedures. For many within the municipality, especially those with no previous exposure to PSS models, this change can feel disruptive and risky. This behavioural inertia, along with an often limited desire to pay more for sustainability, despite stated ambitions, significantly hampers the actual implementation of service-based contract models.

### 6.2.4 Regulatory Barriers

From a regulatory perspective, municipalities face constraints that limit flexibility in adopting new contract models. One major problem is the growing formalisation of sustainability standards, including the requirement that national infrastructure projects utilise the environmental cost indicator (MKI) as award criterion. Although such standards encourage procurement that is environmentally conscious, they may also limit the flexibility of how sustainability is defined or implemented within a PSS framework.



Additionally, many municipalities operate under existing policies that predetermine aspects such as material use, road widths, or public space design. These regulations, often set in stone, leave little room for contractors to propose alternative solutions, even within a performance-based model. The rigidity of policy frameworks can thus limit the creative potential and adaptive benefits that PSS contracts are meant to provide.

### 6.2.5 Contextual Barriers

Several additional barriers stem from broader contextual factors and uncertainties about the long-term implications of PSS adoption. The extended contract durations associated with service-based models, which can range from 10 to 25 years, raise questions regarding continuity, memory, and reliability. Municipal staff may change over time, and initial contract agreements or intentions may be forgotten, jeopardising the contract's effectiveness in subsequent phases.

Concerns have also been raised over contractors' dependability over extended periods of time. In the event that a contractor files for bankruptcy, the municipality can be left with an incomplete project or ambiguous responsibilities, a situation for which there are currently few explicit measures. These uncertainties contribute to a risk-averse mentality among clients.

Furthermore, the added benefit of using a service-based contract when more traditional methods may equally produce the intended sustainability results was a significant consideration. In a couple of pilot projects, clients and contractors first investigated a product-service model before determining that the suggested sustainable solution, like re-galvanizing guiderails, could also be successfully executed under a conventional contract. This sparked debate on the exact advantages of using a service model when it added expense and complexity. In these situations, stakeholders considered whether the PSS framework offered enough value addition over what could be achieved using the traditional contractual and procurement processes. These reflections emphasise the significance of clear value propositions and contextual fit when adopting new contract forms.


*Figure 13: Barriers from the client's perspective*

## 6.3 Comparison of Barriers from the Literature and Pilots of The Circular Road

Chapter 2.3 provided an overview of barriers to PSS implementation in the construction industry as identified in existing literature. Building upon this theoretical foundation, this research further explored how these barriers manifest in the infrastructure sector by analysing the eight Circular Road pilot projects through extensive stakeholder interviews. By comparing theoretical insights with empirical findings, the research aimed to understand whether the barriers described in the literature were also experienced by project participants, and whether additional, context-specific barriers emerged within the infrastructure domain.

To provide a comprehensive overview, a comparison table was created (Table 7), listing all barriers identified through both the literature review and the empirical research. For each barrier, the table indicates whether it was recognised in existing literature, observed in the pilot projects, or both. This systematic comparison highlights which barriers observed in the literature remain relevant in practice, where gaps between the construction sector and the infrastructure sector exist, and where new barriers emerged that warrant further attention.

Figure 14 below visualises these findings by categorising the barriers into five dimensions: financial, organisational, behavioural, regulatory, and contextual. For each category, the number of barriers identified in literature, in pilots, or in both, is represented.

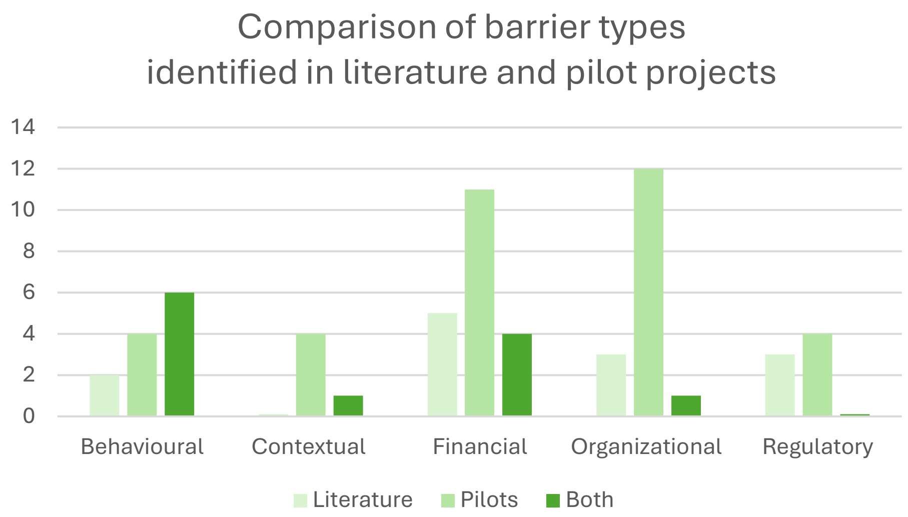


*Figure 14: Comparison of barrier types identified in literature and pilot projects*



As shown, financial barriers were most prominent, not only being the most frequently observed overall but also showing significant overlap between literature and pilots, underlining their structural nature. However, pilots identified more financial barriers than literature alone, suggesting additional practical complexities that are not yet fully reflected in academic discourse. Organisational barriers were also frequently reported in the pilots, though with less overlap with literature. This indicates that the shift from traditional models to service-based models in infrastructure settings may require deeper structural changes than what is commonly described in existing studies. Similarly, many organisational issues observed in pilots appear to be underreported in the broader PSS literature.

Behavioural barriers were relatively balanced across sources but with some important distinctions. While literature often highlights behavioural resistance as a theoretical concern, pilot findings indicate a wider and more diverse set of behavioural challenges in practice, including staff reluctance and low willingness to pay for sustainability. Contextual barriers were primarily observed in pilots. Their absence in literature suggests that these dimensions are highly project-specific and only surface during real-world implementation, particularly in infrastructure settings. Regulatory barriers were discussed relatively little in both sources, and did not overlap. This may indicate that while regulation is a potential constraint, its form and impact are highly context-dependent, and perhaps not yet fully captured in existing studies.

*Table 7: Comparison of PSS barriers identified in literature and pilot projects*

| Barriers | Observed in Literature | Observed in Pilots |
|---|---|---|
| **Financial** | | |
| Absence of open-ended budgets | | ✓ |
| Cost transparency vulnerabilities | | ✓ |
| Difficult service fee pricing | | ✓ |

| | | |
|---|---|---|
| Difficulty quantifying savings | ✓ | |
| Double maintenance cost | | ✓ |
| Exclusion for SMEs | ✓ | ✓ |
| Fee structure unclear | | ✓ |
| Fragmented budgets | | ✓ |
| High initial investment | ✓ | ✓ |
| High interest rates | | ✓ |
| Lack of knowledge of internal expenditures | | ✓ |
| Low profitability | ✓ | |
| MKI bonus budget limit | | ✓ |
| No cost benchmark | | ✓ |
| Perceived market unwillingness to pay | ✓ | |
| Public vs private financing | | ✓ |
| Reluctance to change profitable business model | ✓ | |
| Residual value calculation | ✓ | ✓ |
| Residual value disputes | ✓ | ✓ |
| Uncertain cash flow | ✓ | |
| **Organizational** | | |
| Accountability & oversight | | ✓ |
| Capacity shortage | | ✓ |
| Changes in organizational processes | ✓ | ✓ |
| Citizen confusion | | ✓ |
| Cultural shift required | ✓ | |
| Duplication of municipal system | | ✓ |
| Incompatible financial systems | | ✓ |
| Insufficient project scope | | ✓ |
| Internal buy-in difficulties | | ✓ |
| Lack of mandate | | ✓ |
| Need for new capabilities | ✓ | |
| Organizational inertia | ✓ | |
| Parallel maintenance structures | | ✓ |
| Parallel oversight structures | | ✓ |
| Public safety risk retention | | ✓ |
| Short contract durations | | ✓ |
| **Behavioural** | | |
| Change in mindset from ownership to usage | ✓ | |
| Control reluctance | | ✓ |
| Industry conservatism | ✓ | ✓ |
| Limited PSS knowledge | ✓ | ✓ |
| Limited room for innovation | | ✓ |
| Low willingness to pay more | ✓ | ✓ |
| Need for long term relationships | ✓ | |
| Perceived lack of client commitment | | ✓ |
| Preference for status quo | ✓ | ✓ |
| Resistance to process change | ✓ | ✓ |
| Technical staff resistance | ✓ | ✓ |
| View of contractor as profit-focused | | ✓ |
| **Regulatory** | | |
| Fixed local policy constraints | | ✓ |

| | | |
|---|---|---|
| Lack of guidelines & support | ✓ | |
| No sustainable incentives | ✓ | |
| Prescriptive sustainability rules | | ✓ |
| Rigid technical specifications | | ✓ |
| Shifting environmental policies | | ✓ |
| Weak stakeholder collaboration | ✓ | |
| **Contextual** | | |
| Contractor bankruptcy concerns | | ✓ |
| Long-Term continuity risks | | ✓ |
| Small-scale project limitations | | ✓ |
| Uncertainty in sustainability performance | | ✓ |
| Unclear added value of PSS | ✓ | ✓ |

While many barriers were found exclusively in either literature or practice, a notable subset of challenges were observed in both domains, indicating their persistent and structural nature in the implementation of PSS in infrastructure.

Financial barriers such as the exclusion of small and medium-sized enterprises, identified by de Jesus Pacheco et al. (2019)and Vezzoli et al. (2015), were echoed in practice, where SMEs were unable to compete due to limited access to capital or experience with service-based models. Similarly, high initial investment costs, long noted in theoretical research (Annarelli et al., 2016; Inagaki et al., 2022; Moro et al., 2020), emerged as a pressing issue in pilot projects, with contractors highlighting the financial risk of investing in long-term assets without guaranteed returns. A third recurring concern is the difficulty of calculating residual value, particularly when the lifespan of assets extends beyond the contract term. As noted by Schraven et al. (2022), and supported by this study, unclear valuation at end-of-life complicates pricing strategies and increases contractual friction between clients and contractors.



In terms of organisational barriers, the transition to PSS often demands significant changes to internal processes and competencies, as discussed by Moro et al. (2020) and Vezzoli et al. (2015). This finding was substantiated during the pilots, where both customers and contractors found it difficult to transition traditional systems and responsibilities to a service-oriented paradigm.

Several behavioural barriers were also consistently identified in both the literature and practice. These include the conservative nature of the construction sector (Geng et al., 2023), a limited understanding of PSS principles among project actors (Schraven et al., 2022; Teigiserova et al., 2023), and a low willingness to pay more for sustainability, despite stated ambitions (Hayles & Kooloos, 2008). Other behaviour-driven challenges included a general preference for the status quo (Kuo et al., 2010), resistance to changes in operational processes (Moro et al., 2020), and pushback from staff, who were reluctant to shift away from traditional project delivery approaches (Kuo et al., 2010).

Interestingly, no significant regulatory or contextual barriers were observed in both literature and practice. This may suggest that these dimensions are either context-specific or not yet fully explored in the current research landscape, warranting further investigation.

Together, these overlaps confirm that certain financial, organisational, and behavioural barriers are not just concerns for the construction sector but are also reflected in the infrastructure sector. Their recurrence across multiple sources reinforces the importance of addressing these issues when designing and implementing PSS in infrastructure settings.

# Chapter Seven: Discussion

This chapter presents a comprehensive discussion of the key findings from this research, drawing connections between the theoretical foundations established in Chapter 2 and the empirical insights derived from the eight case studies, interviews, FHM analysis, and workshop. Through this analysis, the research seeks to reflect on the alignment between theory and practice in the implementation of PSS in infrastructure. It also evaluates the broader implications for sustainability, collaboration, and contract structuring in the construction sector. The discussion is structured around the three sub-questions that guided this research, examining stakeholder interactions, the influence of revenue models on sustainability, and the barriers to adopting PSS. These insights contribute to a more nuanced understanding of how PSS can be designed and implemented to meet sustainability goals in real-world infrastructure projects.

## 7.1 Interpretation of the Results

This section interprets the findings in relation to the three sub-questions posed in this research. It explores how clients and contractors interact within PSS frameworks (Sub-question 1), how different types of revenue models relate to the inclusion of sustainability measures (Sub-question 2), and what types of barriers hinder the successful implementation of PSS in infrastructure (Sub-question 3).

### 7.1.1 Stakeholder Dynamics

The FHM proves to be a valuable analytical tool for structuring PSS and understanding the allocation of responsibilities between clients and contractors. It provides insight into how project demands are translated into functional outcomes and how much design freedom is left to the contractor. However, despite its potential, the FHM is not widely used in practice within the construction sector.



During the workshop conducted as part of this research, participants acknowledged the usefulness of the FHM in clarifying project objectives and mapping stakeholder responsibilities. Nevertheless, it became clear that the model lacks practical accessibility. Several participants raised questions about the model's structure and terminology, indicating that the FHM is not sufficiently intuitive for practitioners unfamiliar with its theoretical background. This suggests a need to adapt or simplify the model for real-world application, particularly in the early phases of project development.

The workshop and interviews also revealed a common sentiment among contractors: a desire for greater freedom and earlier involvement in the project development process. Contractors emphasized that early engagement and co-creation could enable them to propose more innovative and sustainable solutions. However, many reported that clients were reluctant to relinquish control over design specifications or performance criteria, limiting the space for innovation and diminishing the collaborative spirit intended by the PSS model.

These findings highlight a recurring tension in PSS implementation, between the control traditionally held by public clients and the flexibility needed by contractors to innovate. While the PSS framework theoretically promotes long-term collaboration and joint value creation, in practice, stakeholder dynamics are often shaped by risk aversion and trust issues. For PSS to fully deliver on its sustainability potential, a shift is required in how roles and responsibilities are shared. This includes establishing mutual trust, encouraging shared risk-taking, and providing contractors with more autonomy to explore alternative, sustainable solutions during the early phases of a project.

### 7.1.2 Misalignment Between Theoretical and Practical Revenue Models

An important finding of this research is the noticeable discrepancy between the revenue models theoretically suggested by the FHM and those applied in practice across the pilot projects. Only two of the eight projects implemented a payment structure that matched the model indicated by the FHM analysis. Most projects still relied on traditional structures such as input- or availability-based models, even in cases where performance-based mechanisms would have better aligned with the project's functional goals and sustainability ambitions.

This misalignment can largely be attributed to the absence of the FHM as a design tool during the early phases of project development. Without using the FHM to guide the structuring of responsibilities and value delivery, clients often defaulted to familiar contractual forms, overlooking opportunities to financially incentivise innovation and long-term sustainability. Applying a theoretical payment model early in the process could help link stakeholder roles to performance outcomes, ensuring that payment structures actively support project objectives, particularly in sustainability and lifecycle performance.

### 7.1.3 Sustainability in PSS

Previous research suggests that PSS can contribute to sustainable measures in many ways. Some studies also linked the revenue model to sustainability. For example, Saccani et al. (2024) suggested that payment mechanisms play an important role in shaping incentives that support sustainable development, the results of this research did not confirm this assumption. The analysis showed that projects with different types of revenue models were all capable of incorporating sustainable measures. However, a more consistent pattern emerged around the degree of freedom granted to contractors. Projects in which contractors had greater flexibility, typically those that aligned theoretically with more performance-based models, tended to demonstrate higher levels of sustainability integration.



Importantly, interview findings reinforced the idea that it is not the revenue model that drives sustainability. Instead, participants emphasised that the shift in mindset, the focus on collaboration, and open discussions around sustainability were the key enablers of sustainable outcomes. Contractors in particular noted that when they were trusted with more autonomy, they could propose innovative and resource-efficient solutions. This suggests that while the revenue model can support sustainability, it is ultimately the collaborative process and the space for innovation that determine the sustainability outcomes of a project. Thus, fostering an environment of mutual trust and open dialogue, paired with a flexible contract structure, appears more critical to sustainability than the formal revenue mechanism itself.

### 7.1.4 Barriers

While several barriers to implementing PSS in the construction industry have been identified in existing literature, this research reveals that not all of these barriers are equally relevant or observable in the infrastructure sector. The barriers documented in literature generally reflect broader experiences from across the construction industry, whereas the findings from this study, based on infrastructure-specific pilot projects, highlight more contextualised and sector-specific challenges. Out of the full set of barriers reviewed, only a subset was found to overlap between prior studies and this research, with most commonalities occurring in the behavioural category, including industry conservatism, limited knowledge of PSS, and resistance to procedural change.

In contrast, the barriers observed in infrastructure projects were largely financial. Interviews and the workshop highlighted several recurring issues, including high interest rates for private market actors, difficulties in calculating residual value, challenges in setting appropriate service fees, and uncertainty about long-term cost savings. These findings indicate that while academic models often highlight such financial risks in theory, their manifestation in practice is highly context dependent. For example, these financial challenges were especially pronounced in projects where responsibilities were fragmented across stakeholders or when there was a lack of clear long-term budget planning on the client side.

Organisational and behavioural challenges also emerged as persistent barriers, including the need for internal restructuring and resistance to new working methods. A particularly illustrative example came from both client and contractor perspectives: in several projects, implementing a PSS required setting up a parallel operational system while an existing one was still in place. For instance, in some municipalities, maintenance tasks like grass cutting were already embedded in the existing municipal system. When a contractor was assigned to perform such tasks under a new PSS contract for a specific district, this created a duplication of efforts and infrastructure, with the municipality needing to adjust its own system and the contractor having to establish a separate one. This phenomenon, described by stakeholders as parallel systems, appeared especially prevalent in smaller-scale projects, such as within individual neighbourhoods or districts. By contrast, larger-scale projects, such as those managed at the provincial level, seemed less affected by this issue due to their broader scope and more integrated management structures.

Overall, this research contributes to a more nuanced understanding of how barriers differ between general construction settings and infrastructure-specific applications of PSS. While the literature often presents financial and organisational challenges as broadly applicable, this study reveals that factors such as project scale, the existing institutional environment, and the degree of stakeholder integration significantly shape how these barriers emerge in practice. As such, although academic typologies offer valuable frameworks, the findings suggest that addressing barriers effectively requires a context-sensitive approach tailored to the infrastructure domain. Overcoming these barriers will require further research and case-based learning. In the meantime, early and open dialogue between clients and contractors to align expectations and co-develop viable financial frameworks can play a crucial role in navigating these challenges.



## 7.2 Practical Implications

This research is closely connected to The Circular Road partner program, which aims to promote the implementation of PSS within the infrastructure sector. It presents findings based on a unique research approach involving eight real-time pilot projects, three of which are currently ongoing, while the remaining five have already been implemented and analysed retrospectively. This combination of post-implementation and in-progress cases allows for both reflective insight and observation of current practices. Thus, the results provide a practical guideline for stakeholders applying PSS in the infrastructure sector in particular and the construction industry in general. To translate these results effectively into practice, stakeholders involved in the program are encouraged to critically assess the applicability of these findings to their specific contexts.

First, the FHM proved to be a valuable tool for mapping the structure of a project, offering clarity on the distribution of responsibilities between clients and contractors. During the workshop conducted as part of this study, participants confirmed that the FHM facilitated a clearer understanding of the project scope and roles. As such, the FHMs developed for this research could serve as practical instruments for ongoing or upcoming projects, especially those still in early development stages, by supporting structured dialogue and joint understanding among stakeholders.

Second, the observed misalignment between theoretical revenue models, derived using the FHM, and those applied in practice suggests that revenue mechanisms are often not explicitly tailored to the structure and objectives of the project. This finding provides valuable insight into how revenue models in PSS are currently being applied and where improvements can be made. As revenue models play a central role in shaping incentives, responsibilities, and outcomes, the results of this research can serve as a foundation for developing more suitable and effective payment structures. Stakeholders are therefore encouraged to critically evaluate whether the selected revenue model supports the intended functional and sustainability objectives of the project and to consider adjustments where needed to better align financial mechanisms with long-term performance goals.

Third, the study reveals that while revenue models do shape financial structures, they are not in themselves the primary drivers of sustainability. Instead, the degree of freedom granted to contractors, often correlated with more performance-oriented revenue models, was found to have a more direct influence on the integration of sustainable solutions. This suggests that enabling greater flexibility and early contractor involvement may be more effective levers for promoting sustainability than revenue structure alone.

Finally, the comprehensive overview of barriers identified in both theory and practice provides actionable insights for future project planning. By understanding the financial, organisational, behavioural, regulatory, and contextual challenges that have hindered PSS implementation in the pilot projects, practitioners can proactively address these issues. This could involve investing in internal capacity building, rethinking procurement procedures, or conducting further research to resolve specific uncertainties such as residual value calculation. These insights contribute to a more informed and strategic application of PSS in infrastructure, supporting the transition toward more sustainable and circular practices.

## 7.3 Limitations



Although this research provides valuable insights into the implementation of PSS and their associated revenue models in infrastructure, several limitations must be acknowledged. First, all case studies were drawn from the same collaborative partner program, The Circular Road, which may have introduced selection bias. Projects conducted within this program may have benefited from pre-existing relationships, shared sustainability ambitions, and a higher degree of trust between parties. This environment could have resulted in more open communication and willingness to experiment with circular solutions than in typical market conditions. Additionally, the respondents were aware that findings would be shared within the program, potentially influencing them to portray their own contributions and project outcomes in a more favourable light.

The structure of the partner program also introduced unique conditions that could affect generalizability. For example, tender exemptions were sometimes applied, and in most cases, the contractor was already predetermined, which eliminated competition and could have affected the business dynamics typically associated with PSS implementation. Moreover, the recurring involvement of the same contractor across different projects could have enhanced consistency and trust but may also have limited the range of perspectives and challenges encountered. As such, these findings may not be fully transferable to contexts with more competitive procurement procedures or less institutional alignment.

From a methodological standpoint, the FHM provided a strong analytical framework for assessing stakeholder roles and revenue models, but it also has limitations. While the FHM presents a clear typology of revenue models, in practice, the distinction between them is often blurred, with hybrid approaches being more common. This complexity is not fully captured in the model, which may lead to oversimplification when interpreting theoretical revenue mechanisms.

Additionally, the scope of the sustainability analysis was limited to five projects, which restricts the ability to draw general conclusions about the relationship between revenue models and sustainability outcomes. Additional studies across a broader range of projects are needed to validate the patterns observed. Furthermore, given that the impact of sustainability measures was not quantitatively assessed, it remains unclear how significant the observed measures were in terms of environmental performance. As such, more empirical research is needed to validate these mechanisms and their outcomes in other projects and settings.

Furthermore, this study exclusively examined public clients, leaving open the question of how PSS dynamics may differ in privately commissioned infrastructure projects, where contractual incentives and organisational structures can vary significantly.

Despite these limitations, this research contributes to a growing understanding of PSS implementation in infrastructure and offers a foundation for future investigation in more varied and competitive contexts.

# Chapter Eight: Conclusion

This research set out to examine how PSS contracts, particularly the design and application of revenue models, can contribute to advancing sustainability within the construction industry. In doing so, it also explored the roles and interactions of stakeholders, as well as the practical barriers encountered during implementation. This chapter presents the main conclusions of the study, structured around the research sub-questions and the overarching research question. It concludes with recommendations for future research based on the findings and limitations of this work.

## 8.1 Conclusions of the research questions

This section summarises the findings for each of the three sub-questions, followed by the overall conclusion to the main research question. The conclusions are based on the synthesis of literature, case study analysis, stakeholder interviews, and workshop observations. The conclusions presented here are based on a qualitative and exploratory investigation. They reflect patterns and insights from a specific context, the Circular Road pilot projects, and should be interpreted as indicative rather than conclusive.

*SQ1: How do the client and contractor collaborate within a Product-Service System to align service delivery with sustainability goals throughout the project lifecycle?*

This research suggests that collaboration between client and contractor in PSS is shaped less by formal structures and more by the level of early co-creation and the degree of freedom granted to the contractor. Using the FHM by Van Ostaeyen et al. (2013), it becomes evident that the client initiates the process by defining high-level project demands. The extent to which the contractor is permitted to contribute to meeting these demands, either at the functional level (i.e., defining how the demands are met) or merely at the structural level (i.e., delivering predefined solutions), is determined by how much design and decision-making freedom the client is willing to delegate. Across the cases, it became evident that when contractors were engaged earlier and granted more functional freedom they were better able to introduce sustainability measures.

Across the analysed projects, all included sustainability measures. In cases where contractors contributed at higher levels of the FHM, a greater share of sustainability measures was observed in relation to the total number of elements in the model. In projects where input was limited to the structural level, the number of sustainability measures was generally lower.

*SQ2: How do different payment mechanisms relate to the implementation of sustainable and innovative solutions in Product-Service Systems?*

No direct or consistent link was observed between the specific type of revenue model used and the number of sustainability measures implemented. The case studies reveal that different payment mechanisms, ranging from input-based to performance-oriented models, were used across projects, and were all capable of integrating sustainable measures.

Additionally, the theoretical payment models derived from the FHM often did not match the mechanisms applied in practice. Stakeholder interviews indicated that the presence of sustainable and innovative solutions was more closely associated with how sustainability was addressed in the project process and the level of collaboration, rather than with the specific payment mechanism used.

*SQ3: What are the barriers to implementing the Product-Service System in the infrastructure sector?*

The research identified a wide range of barriers that hinder the implementation of PSS in the infrastructure sector. Through stakeholder interviews and a workshop, barriers were categorised across five key dimensions: financial, organisational, behavioural, regulatory, and contextual. Contextual barriers emerged uniquely in this study and reflect challenges specific to the nature of infrastructure projects, such as unclear added value of PSS compared to traditional models, and uncertainties around long-term performance commitments.

Financial barriers were most frequently reported and varied depending on the stakeholder group. These barriers included high upfront investments, exclusion of SMEs, challenges in calculating service fees and residual value, and the risk of double maintenance costs in certain contract arrangements. Organisational barriers included the need for internal restructuring and adjustments to new operational models. Behavioural challenges such as industry conservatism, limited knowledge of PSS among stakeholders, low willingness to pay more for sustainable alternatives, and resistance to process change were also commonly noted. While regulatory barriers were mentioned less frequently, the lack of guidelines and support and rigid local policy was still perceived as a constraint.

Although some barriers observed in this study were consistent with those documented in previous literature on PSS in the broader construction industry, such as industry resistance and the need for organisational change, this research uncovered a much wider array of challenges specific to the infrastructure context. Furthermore, the findings suggest that while literature provides a useful typology of barriers, actual manifestations are highly dependent on the project scale, institutional setting, and degree of integration between stakeholders. A context-specific approach is therefore essential to understanding and mitigating PSS implementation challenges.

### *Main research question: How can different revenue models within Product-Service Systems be structured to stimulate sustainability in the construction industry?*

This research suggests that while revenue models vary across PSS projects, their structure alone may not directly determine sustainability outcomes. Instead, other factors, such as contractor autonomy and early collaboration, appear to play a more influential role. The analysis of case studies revealed that projects with varying revenue mechanisms were all capable of integrating sustainable measures, and no clear, linear relationship was observed between the type of payment model and the percentage of sustainability measures implemented. These revenue mechanisms did not consistently align with the theoretical models suggested by the FHM, and only a few cases demonstrated a match between the theoretically appropriate and practically implemented revenue model.



However, there appears to be a positive association between performance-based models and the degree of contractor autonomy, under which sustainability outcomes tended to be more pronounced. Thus, it may not be the type of revenue model that matters most, but how it is applied within the broader project and relational context. While the structure of the revenue model varied between projects, all case studies implemented sustainability measures to some extent. The presence or absence of certain features, such as contractor involvement levels and alignment between theoretical and practical models, was recorded across cases, offering insights into how revenue models were constructed and applied in relation to project sustainability objectives.

## 8.2 Recommendations for future research

This research has provided valuable insights into the implementation of PSS in infrastructure, particularly regarding stakeholder collaboration, revenue model design, and sustainability integration. However, several areas warrant further exploration to enhance both theoretical understanding and practical application of PSS in the construction industry. Based on the findings and limitations of this study, the following topics are recommended for future research:

- **Adapting the FHM for practical use**
  While the FHM by Van Ostaeyen et al. (2013) proved useful for analysing stakeholder roles and determining revenue model alignment, this study found that its application in practice is limited by its complexity and abstract terminology. Future research could focus on refining the FHM to make it more intuitive and accessible for practitioners in infrastructure projects. This

may include developing simplified visual tools, incorporating user-friendly language, or integrating case-based examples that bridge theory and practice.

- **Designing revenue models as strategic levers:**
  Revenue models in this study were often misaligned with theoretical expectations, and their potential to incentivize sustainability was underutilised. Future research should explore how financial mechanisms can be intentionally designed to act as levers that support long-term environmental and social goals.
- **Exploring how to overcome implementation barriers**
  This study identified a range of financial, organisational, behavioural, regulatory, and contextual barriers that hinder the adoption of PSS in infrastructure. Many of these challenges were observed to be more prominent in practice than in theory. Future research should investigate concrete strategies, tools, and policy interventions to overcome these barriers.
- **Validating findings beyond the Circular Road program**
  As this study focused exclusively on pilot projects within the Circular Road partner program, its findings may reflect the unique dynamics of that collaborative setting. Future research should test whether similar stakeholder behaviours, revenue model patterns, and sustainability outcomes occur in infrastructure projects run by other organisations or under different procurement conditions. Comparing outcomes across varied institutional settings, including private-sector clients and competitive tenders, will help assess the broader applicability of the conclusions drawn here.

## Chapter Nine: Reflection

This graduation journey began with my interest in contracts and sustainability. As mentioned in the preface, I was quickly connected with Leon, who referred me to Daan. He played a key role in helping define my research focus. The use of performance-oriented contracts in infrastructure remains relatively underexplored, which made it especially rewarding to contribute to this emerging field. I had already been in touch with dutch process innovators before the research was formally shaped, and their enthusiasm for the topic helped kick-start the project smoothly.

Writing a master's thesis is undoubtedly a challenging process, but overall, I was surprised by how well it unfolded. While there were inevitable ups and downs, I received continuous support from my supervisors, which helped me navigate the various phases of the project. The research proposal phase went well, and my supervisors' enthusiasm gave me a strong start. However, I did face some difficulties in selecting the right methodology. After a period of critical reflection and incorporating feedback, I revised my initial approach, which ultimately improved the quality of my research.

One of the more challenging moments came just after formally starting my thesis. I struggled with knowing where to begin and how to break the process into manageable steps. Kaleem's guidance was crucial during this time, he helped me approach the thesis one question at a time, which brought clarity and direction. Another delay arose from the time it took to schedule interviews, which taught me the importance of starting early when coordinating with others.

Once the interviews began, I gained momentum and collected insightful data. The interviewees from the Circular Road projects were genuinely enthusiastic about my research, which further motivated me. Their eagerness to learn from my findings and apply them in practice gave me a sense of real-world impact that was deeply rewarding. Organising the workshop and seeing how my insights supported an ongoing project was one of the most inspiring moments of the entire process.



In contrast, the period of intensive literature review was less energising. I had experienced some loneliness during my bachelor thesis and was concerned it might happen again. However, this time I took active steps to stay connected, working from the university library and surrounding myself with fellow thesis students helped keep my motivation high during this more solitary phase.

The final stretch, where I had to synthesise all my findings into a cohesive story, was intense. With a tight deadline and a perfectionist mindset, this phase became quite stressful. I especially struggled with defining and operationalising sustainability within the projects. Nonetheless, I managed to bring everything together in the end.

I have learned a great deal throughout this graduation process, about both research and myself. While I have always valued structure and high standards, I learned to accept that things do not always go according to plan. I also realised that sharing unfinished work and seeking early feedback is not only acceptable, but essential for growth. Although I was hesitant at first, this shift helped me develop both personally and academically.

Looking back, I am proud of the work I have done and the journey I took to get here. It was not always easy, but I gave it my best effort at every stage. With the experience I now have, I might do some things differently, but I am grateful for what I have achieved and all that I have learned.

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# Appendix A: Functional Hierarchy Models from Schraven et al.

## 11.1 Old FHM of the Replacement of Bridge Decks – Amersfoort

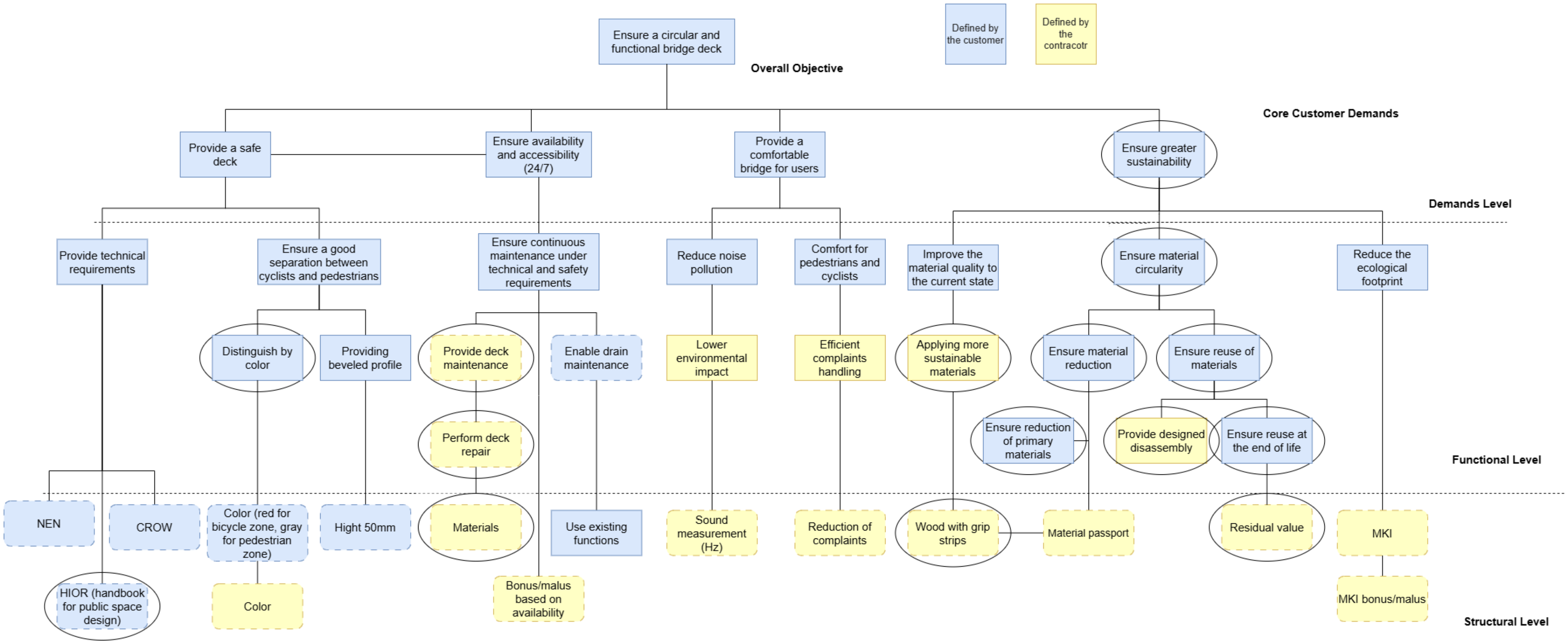



*Figure 15: FHM by Schraven et al. (2022)of the Replacement of Bridge Decks in Amersfoort*

## 11.2 Old FHM of the Reconstruction of Dr. J.P. Heijerlaan – Amersfoort

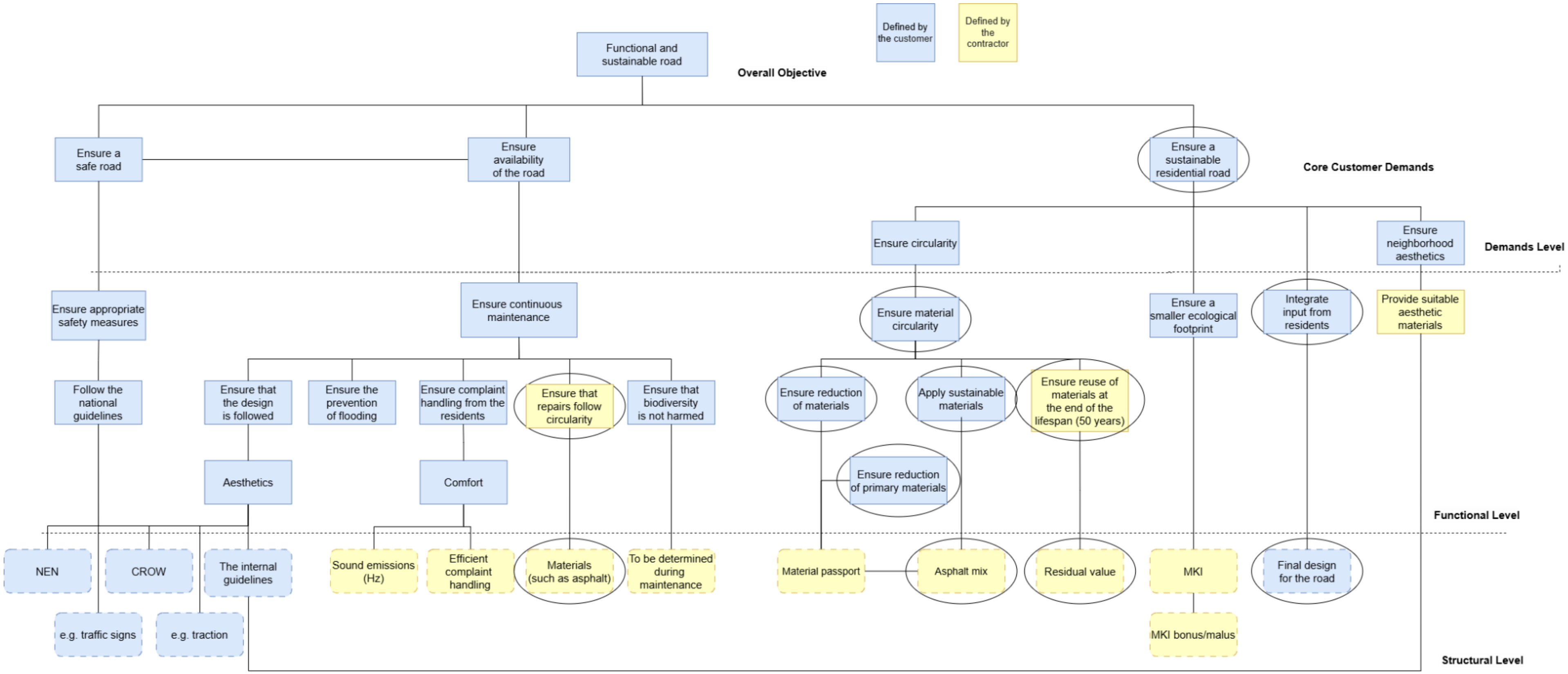



*Figure 16: FHM by Schraven et al. (2022) of the Reconstruction of Dr. J.P. Heijerlaan in Amersfoort*

## 11.3 Old FHM of the Sustainable Road Lighting – North Brabant

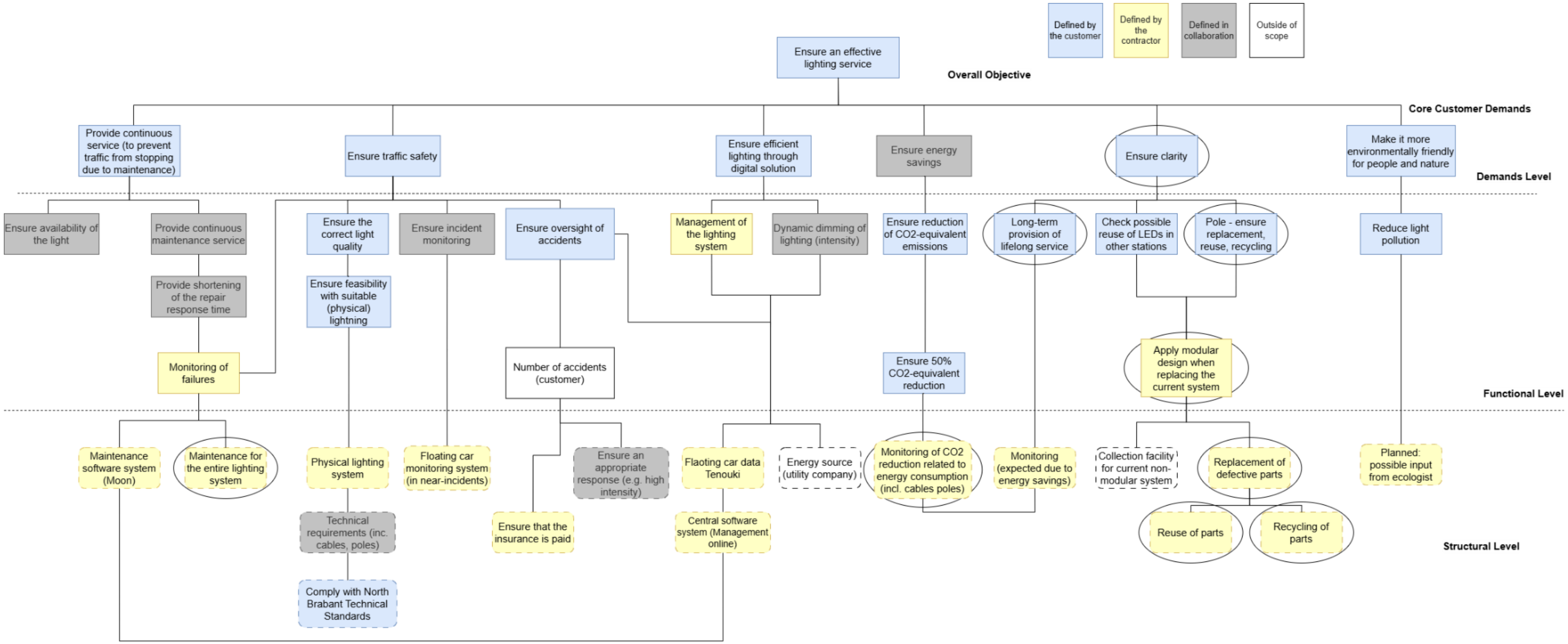



*Figure 17: FHM by Schraven et al. (2022) of the Sustainable Road Lighting in North Brabant*

## 11.4 Old FHM of the Sustainable Guiderails – North Holland

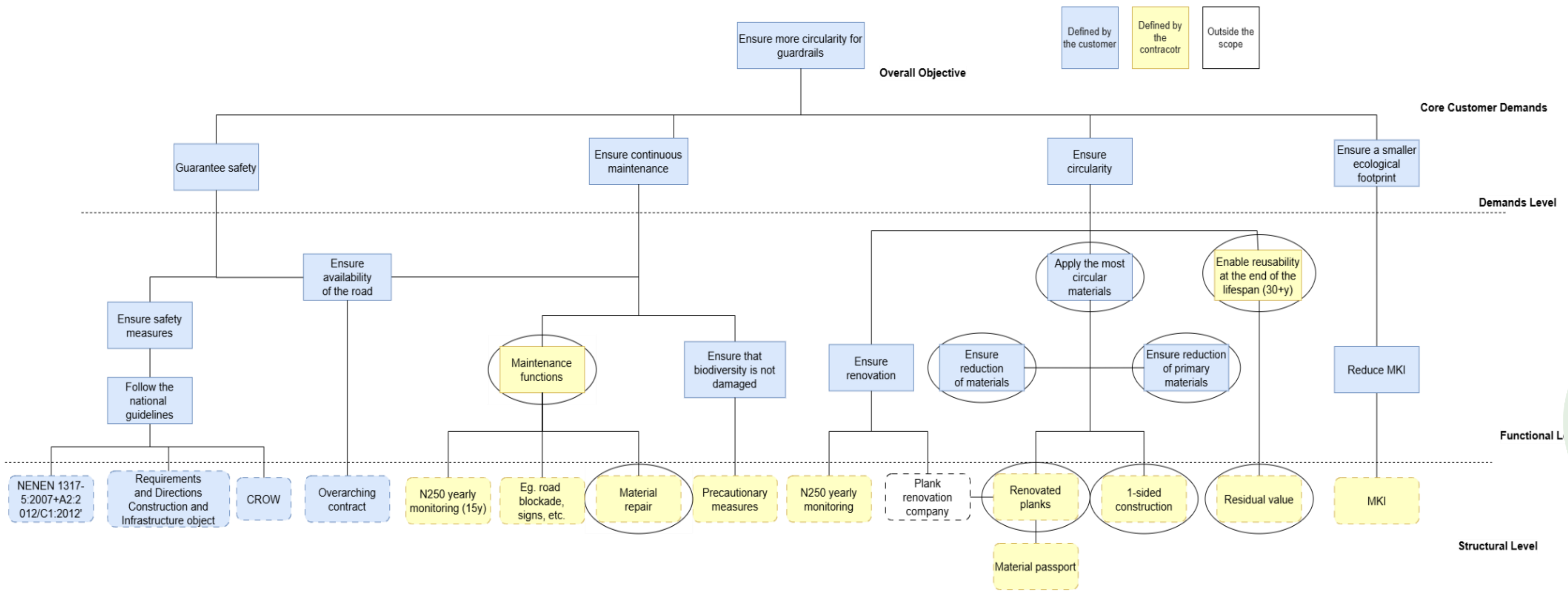
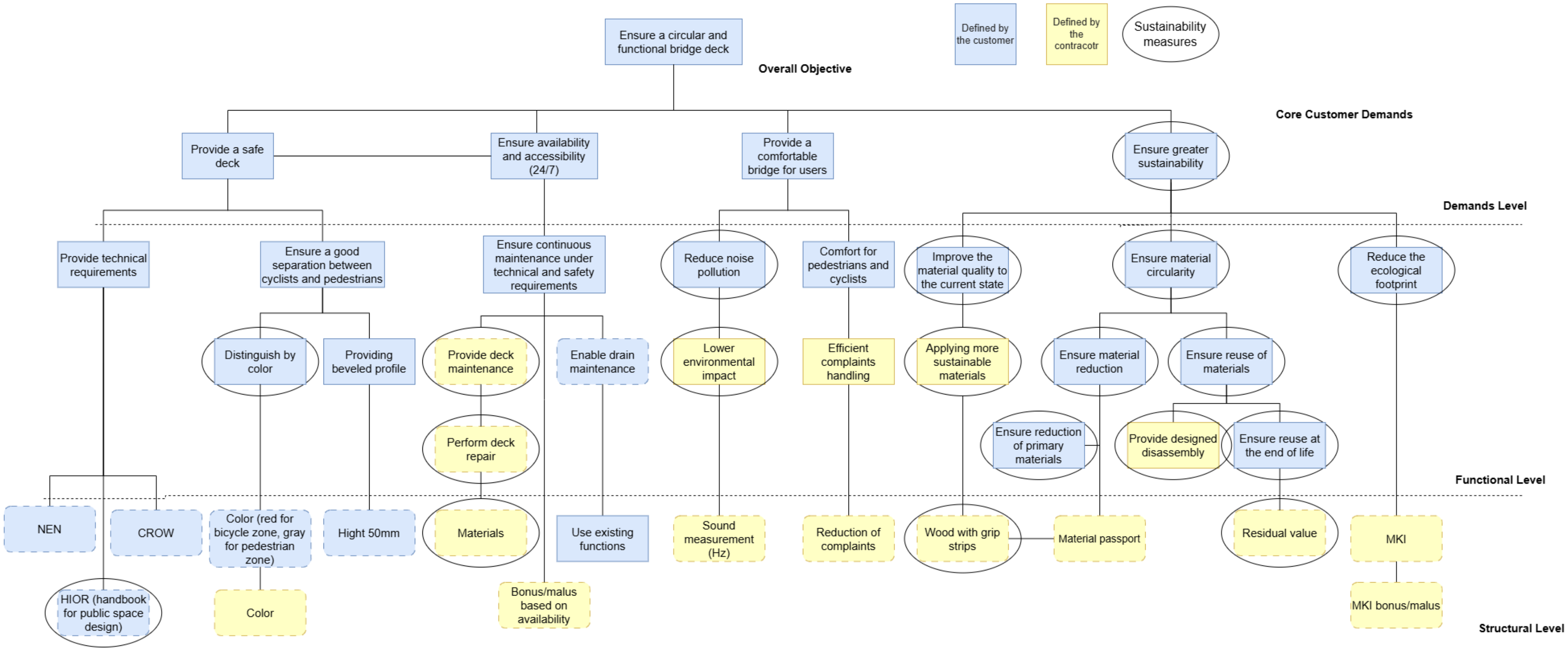



*Figure 18: FHM by Schraven et al. (2022) of the Sustainable Guiderails in North Holland*

# Appendix B: New Functional Hierarchy Models adjusted for sustainable measures

## 12.1 New FHM of the Replacement of Bridge Decks – Amersfoort





## 12.2 New FHM of the Reconstruction of Dr. J.P. Heijerlaan – Amersfoort

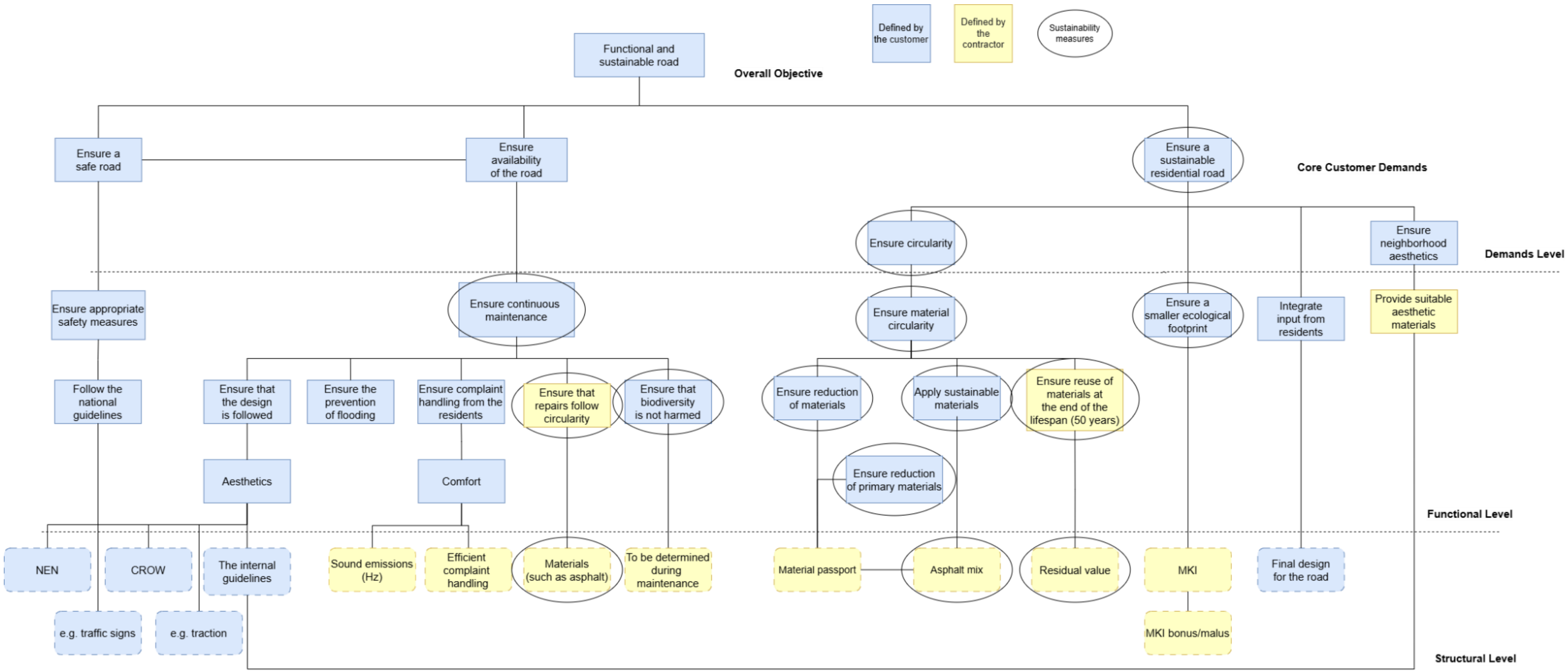



*Figure 19: FHM adjusted for the sustainability measures of the Reconstruction of Dr. J.P. Heijerlaan in Amersfoort*

## 12.3 New FHM of the Sustainable Road Lighting – North Brabant

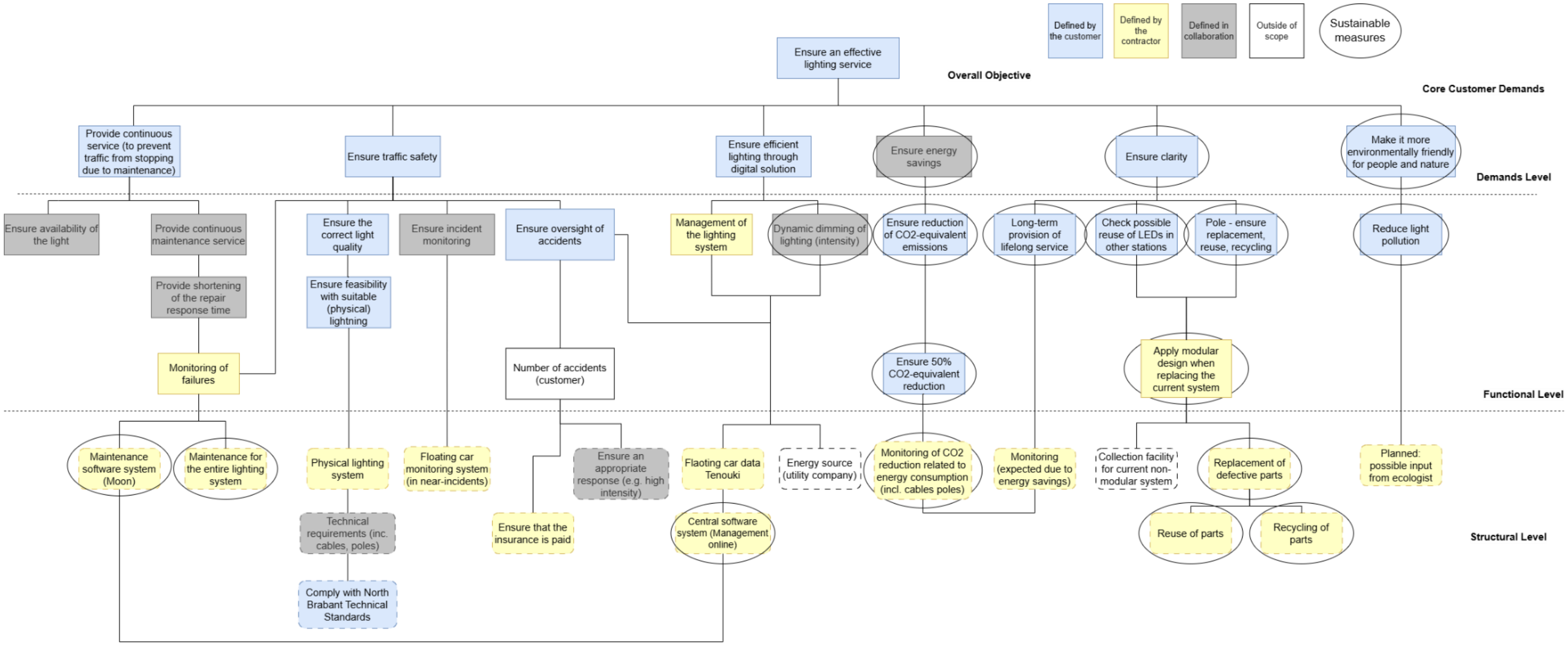



*Figure 20: FHM adjusted for the sustainability measures of the Sustainable Road Lighting in North Brabant*

## 12.4 New FHM of the Sustainable Guiderails – North Holland

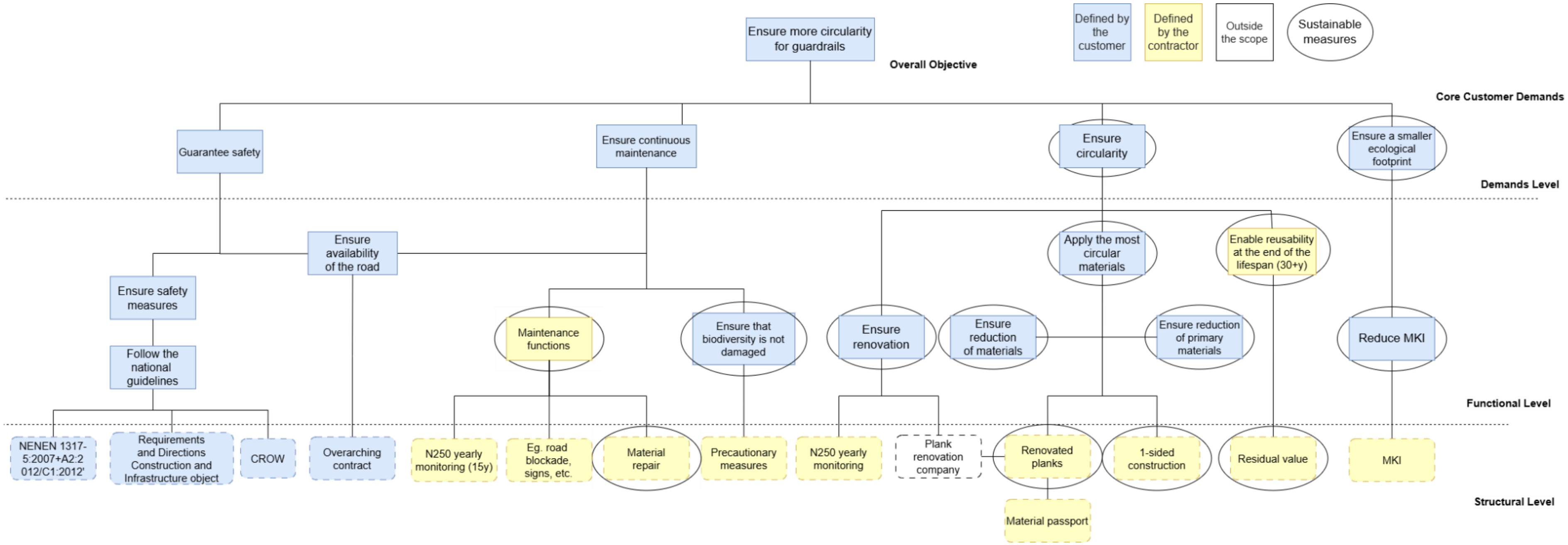



*Figure 21: FHM adjusted for the sustainability measures of the Sustainable Guiderails in North Holland*