

AT FAÇ[AD]E VALUE:

REVISITING THE ADDED VALUE OF FAÇADE PRODUCT SERVICE SYSTEMS FOR SEMI-PUBLIC REAL ESTATE OWNERS.

Theme 5: Sustainability transitions and the transformation of port cities

MSc Thesis

Management in the Built Environment (MBE)

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ABSTRACT

This thesis investigates the role of Façade-as-a-Service (FaaS) within the framework of circular economy business models, specifically focusing on its value for semi-public real estate owners and users. The research is motivated by the growing demand for sustainable solutions in the built environment as global efforts to mitigate climate change and resource scarcity intensify. Façade Product-Service Systems (PSS) offer a promising alternative to traditional façade procurement by integrating both the product (the façade) and associated services (such as maintenance and energy management) into a single, long-term offering. The research aims to answer the question:

HOW DO FAÇADE PRODUCT SERVICE SYSTEMS (PSS) OFFER VALUE TO SEMI-PUBLIC REAL ESTATE OWNERS”

The thesis builds on a detailed literature review of PSS, value creation, and current valuation methodologies, identifying key theoretical foundations and knowledge gaps. The core research question centres on understanding how Façade PSS creates value for semi-public real estate owners. To answer this, the study employs a mixed-method approach, combining qualitative and quantitative research, including case studies, interviews, and financial simulations. The Civil Engineering (CiTG) building at TU Delft is selected as a case study to test the practical viability of the FaaS concept. Central to the analysis is the development and application of a financial model, particularly focusing on the Total Cost of Ownership (TCO) and Total Value of Ownership (TVO) frameworks. A sensitivity analysis assesses the financial risks and uncertainties inherent in long-term service contracts.

The empirical findings reveal that while technological readiness for FaaS is relatively high, financial and cultural barriers still hinder widespread adoption. Key challenges include the lack of standardised appraisal methods for real estate with integrated façade product service systems, as well as the perceived risks associated with circular business models. However, the results suggest that when properly implemented, FaaS can offer significant value to building owners by reducing operational costs, enhancing sustainability, and aligning with long-term portfolio management strategies.

This research contributes to the field of circular real estate by advancing the understanding of façade product-service systems and providing a framework for evaluating their financial and environmental benefits. It also offers practical recommendations for stakeholders interested in implementing FaaS, advocating for a shift towards value-driven, service-oriented approaches in building management. The thesis concludes by identifying future research opportunities, particularly in refining valuation models and exploring scalable financing solutions for circular business models.

KEYWORDS: FAÇADE-AS-A-SERVICE, CIRCULAR ECONOMY, BUSINESS MODEL, TOTAL VALUE OF OWNERSHIP, PRODUCT SERVICE SYSTEMS (PSS), VALUE

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00 EXECUTIVE
SUMMARY

INTRODUCTION

The Paris Agreement seeks to limit global warming to 1.5°C, requiring GHG emissions to peak by 2025 and reduce by 43% by 2030 (UNFCCC, n.d.). The real estate sector, responsible for 42% of global CO₂ emissions, faces significant challenges, with only 15% of properties aligned with the 1.5°C target (CBRE, n.d.; Architecture2030, n.d.). Existing buildings contribute one-third of emissions and will account for two-thirds of the 2050 building stock. The European Green Deal (2021) targets a 60% reduction in building-related emissions, a 14% cut in energy use, and an 18% drop in heating and cooling demand by 2030. Achieving these goals requires doubling current renovation rates (1% annually) and focusing on "deep" retrofits to significantly enhance energy efficiency (Caloia et al., 2022; Initiative, 2020).

The construction sector generates over a third of Europe's waste, with Dutch real estate responsible for 50% of raw material use, 40% of energy consumption, and 30% of water usage (European Commission, 2016; Rijksoverheid, 2016). Population growth, expected to reach 9.7 billion by 2050, will double raw material demand to 186 billion tons annually, exceeding the planet's biocapacity (United Nations, 2023; UNEP, 2017).

To address these challenges, the circular economy promotes reducing, reusing, and recycling materials, extending their lifecycle and reducing waste (Foundation, 2013). The Netherlands plans full circularity by 2050, with an interim goal to halve raw material use by 2030. Circular practices also help mitigate supply chain vulnerabilities, resource scarcity, and environmental degradation, though the sector remains in its early stages (Peirani & Cochard, 2021).

PROBLEM STATEMENT

The built environment is vital for addressing resource resilience and climate change. Challenges like material scarcity, energy costs, and affordable housing demand new approaches in construction and real estate. The Circular Economy (CE) and Product-Service Systems (PSS) offer solutions, shifting focus from ownership to utility, promoting resource efficiency and reuse (Manzini & Vezzoli, 2003; Fischer, Steger et al., 2012).

Façade PSS integrates building envelopes with services, enhancing energy efficiency and user comfort. Façades can account for 40% of initial building costs or over 90% in retrofits (Azcarate-Aguerre, 2023; Azcarate-Aguerre et al., 2022). Pilot studies at TU Delft (EWI, 2017; CiTG, 2019) revealed cultural, regulatory, financial, and technical barriers (Azcarate-Aguerre, 2023). A critical issue is the lack of valuation standards for externalities like comfort, energy savings, and carbon impacts, which undermines equitable financial foundations for PSS (Azcarate-Aguerre, 2023).

Circular models mitigate costs and market risks, offering consistent revenue streams across the value chain (Alix & Vallespir, 2009; Azcarate-Aguerre et al., 2022). Yet scaling is limited by immature material reuse markets, short-term financial tools, and "circular risks," requiring collaboration and realigned incentives (Circle Economy et al., 2016; Fischer & Achterberg, 2016). Innovative business models must balance Total Cost of Ownership (TCO) with Total Value of Ownership (TVO), but robust methodologies for comparing linear and circular contracts are lacking (Rosa et al., 2019; Azcarate-Aguerre, 2023).

Pooling circular projects into investment funds could distribute risks and attract financing, yet research on this approach for façade PSS remains scarce (Achterberg & Van Tilburg, 2016).

SCIENTIFIC RELEVANCE

TU Delft has conducted two pilot projects on façade Product-Service Systems (PSS): the 2017 EWI project focused on technological readiness, and the 2019 CiTG East Facade project (FaaS 1.0) addressed systemic barriers and solutions (Azcárate-Aguerre, 2023). A third pilot, Leasegevel 2.0 I (integrated) Facades-as-a-Service, is being developed but is currently on hold.

This project builds on earlier research with TU Delft faculties, Alkondor Hengelo B.V., and a supplier consortium. Its goal is to validate the implementation of a circular Façade-as-a-Service model in the existing built environment, using the West façade of TU Delft's Civil Engineering building as a case study.

Leasegevel 2.0 aims to unlock scalable energy- and resource-efficient retrofits, driving better decisions in new projects. Success in early phases could build confidence in the sector and catalyze broader FaaS investments. Meanwhile, this research revisits previous drivers and barriers while validating valuation methodologies for FaaS compared to linear alternatives.

RESEARCH QUESTIONS

The Netherlands aims to transition to a sustainable built environment and circular economy by 2050. Façade Product-Service Systems (PSS) present significant potential for achieving this goal. However, their adoption is not yet common, even in ideal scenarios like university living labs.

This research addresses the primary question:

"How do Façade Product-Service Systems (PSS) offer value to semi-public real estate owners?"

Here, "value" encompasses the relative worth, utility, or importance of Façade PSS from both consumer and provider perspectives, evaluated within the context of Total Value of Ownership and product-service offerings.

To answer this, the study explores:

1. **What are Façade PSS?**
2. **What are the current methodologies for valuing Façade PSS?**
3. **What motivates semi-public real estate owners to adopt Façade PSS?**
4. **What challenges do these owners face in using Façade PSS?**
5. **How does Façade PSS compare to traditional façade renovation procurement?**

The research aims to define and measure the value of Façade PSS to support their broader adoption in sustainable real estate practices.

METHODOLOGY

The research consists of four segments: theoretical research, empirical research, financial model and conclusions. Concurrently action research has been done in support of the main sections.

ACTION RESEARCH

Action research is incorporated into this study as a means of capturing insights from unplanned interactions, such as informal conversations and meetings with stakeholders or participants involved in parallel research projects. These interactions often occur outside the structured research framework but provide valuable, real-time data crucial to understanding the dynamic context of Façade PSS.

This participatory and iterative methodology emphasises cycles of planning, action, observation, and reflection, making it particularly suited for the flexible and evolving nature of this study (Kemmis, 1988). Through direct engagement with participants in their environments, action research enables the capture of nuanced perspectives that might otherwise be overlooked. It not only enhances the richness of the data collected but also empowers participants by involving them directly in the research process. By integrating these informal yet insightful contributions into the broader research framework, action research adds depth and practical relevance to the study, ensuring it reflects real-world complexities.

THEORETICAL RESEARCH

The theoretical research component is anchored in a detailed literature review, a foundational aspect of the study. This phase systematically collects, critically evaluates, and synthesises existing knowledge on two core themes: Façade PSS and the concept of Value. The literature review is divided into three distinct stages to build a comprehensive understanding and establish a robust conceptual framework for the research.

The first stage, Defining, focuses on clarifying essential concepts and terminology related to Façade PSS. This involves a thorough examination of Façade PSS, exploring its economic and environmental significance, as well as its characteristics and potential applications in creating sustainable building solutions. The aim is to move beyond simply gathering information to critically assessing and interpreting the existing knowledge base. This stage lays the groundwork for a clear and consistent conceptual framework to guide the research.

The second stage, Collecting, involves identifying and analyzing current valuation methodologies and metrics relevant to Façade PSS. This phase is crucial for understanding the quantitative approaches previously applied to similar systems and their implications for the economic viability and sustainability of building projects. By reviewing and critically evaluating these methods, the research seeks to highlight both their strengths and gaps, establishing a foundation for developing a more comprehensive framework.

The final stage, Synthesizing, integrates the findings from the defining and collecting phases into a cohesive valuation framework: the Total Value of Use (TVU) model. This

model aims to provide a holistic approach to valuing Façade PSS, encompassing both qualitative and quantitative dimensions. It is designed to address the complexities of assessing economic viability and sustainability, ultimately serving as a tool for evaluating and comparing different Façade PSS solutions. The TVU model represents the culmination of the theoretical research phase, offering a novel perspective on valuation that aligns with the goals of circular economy principles.

EMPIRICAL RESEARCH

The empirical research phase combines a single-case study with semi-structured interviews to validate and refine the theoretical framework developed during the literature review. These methods are chosen to bridge the gap between theoretical insights and real-world practices, ensuring a comprehensive understanding of the value offered by Façade PSS.

Single-case study

The single-case study focuses on the Leasegevel 2.0 project at TU Delft, which explores the implementation of integrated Facades-as-a-Service in the existing built environment. This case is uniquely suited for the study due to its pioneering nature and its connection to earlier phases of related research, such as the EWI building in 2017 and the CiTG East Facade in 2019. Both projects are considered part of an ongoing and evolving stakeholder network, making Leasegevel 2.0 not only a longitudinal case but also an embedded one that incorporates multiple stakeholder perspectives. The complexity of the governance structure and the novelty of the project further justify the

single-case approach, as there are no comparable Façade PSS offerings available for analysis at this time (Yin, 2003).

Semi-structured interviews

In addition to the case study, semi-structured interviews play a critical role in the empirical phase. These interviews aim to gather qualitative data from key stakeholders involved in or affected by the Façade PSS concept. Using an interview protocol with open-ended questions, the study ensures flexibility for interviewees to express their views and for the researcher to explore emerging themes in greater depth. This method is particularly effective for uncovering insights that structured surveys might miss, offering a deeper understanding of stakeholder roles, influences, barriers, and drivers (McIntosh & Morse, 2015; DiCicco-Bloom & Crabtree, 2006).

The interview sample is purposive, focusing on "informed individuals" with relevant expertise or experience in Façade PSS. A sample size of eight to twelve participants is targeted to optimise the balance between depth of input and avoiding redundancy (Pendergast & Marr, 1994). Snowball sampling is employed to identify participants, ensuring representation from diverse perspectives. The insights gathered through these interviews are analysed to validate the TVU model, identify patterns, and refine the theoretical framework.

Financial model

A comprehensive financial model was developed to analyse the financial implications of the CiTG case. This includes a Total Value of Ownership/Use (TVO/TVU) calculation from the client's perspective and a

3-statement model and Discounted Cash Flow (DCF) model from the provider's perspective.

To enhance the TVO model, a Monte Carlo simulation has been conducted as a dynamic sensitivity analysis. This technique explores the range of potential outcomes by stochastically varying key input parameters, generating a distribution of results. It helps quantify risks and uncertainties in the financial and operational aspects of Product-Service Systems. The simulation's findings will refine the TVO model, ensuring its robustness and applicability to real-world scenarios characterised by variability and uncertainty.

FINDINGS

This section addresses the main findings from the research by discussing the sub-questions and concluding with overarching insights.

SQ1: WHAT ARE FAÇADE PRODUCT-SERVICE SYSTEMS (PSS)?

Façade Product-Service Systems (PSS) combine façade products with services to deliver tailored solutions to users and building owners. Based on PSS theory, they emphasise outcomes over ownership, offering models like leasing façades, bundling products with maintenance services, or providing comprehensive service contracts. Leasing, in particular, encourages circularity by incentivizing providers to maximise durability, reuse materials, and optimise lifecycle costs (Mont, 2004; Tukker, 2004; van Ostaeyen et al., 2013).

This approach aligns with the idea that "people do not need walls and windows, but comfortable and energy-efficient indoor environments" (Mont, 2004). By treating façades as assets, providers aim to minimise

operational costs and maximise product lifespans, further incentivizing the reuse or remanufacture of components (Baines & Lightfoot, 2013; Azcárate-Aguerre, 2016). Façade PSS thus offer an opportunity to decouple economic growth from resource depletion, supporting the transition to a circular economy.

However, not all façade PSS are inherently circular or sustainable (Mont, 2002). Achieving circularity requires designing façades for disassembly, using sustainable materials, and fostering collaboration among stakeholders, including designers, manufacturers, service providers, and clients. Properly implemented, façade PSS can create regenerative business models that reward efficient and sustainable resource use (Azcárate-Aguerre, 2022a).

SQ2: WHAT ARE THE CURRENT METHODOLOGIES FOR VALUING FAÇADE PSS?

Valuation methodologies for façade PSS include Life Cycle Costing (LCC), Total Cost of Ownership (TCO), Whole Life Costing (WLC), and Total Value of Ownership (TVO). LCC and TCO focus on direct costs—capital, operational, maintenance, and decommissioning expenses—quantified using Net Present Value (NPV) calculations (van Ostaeyen, 2014; Wynstra et al., 2004; Azcárate-Aguerre et al., 2016).

WLC extends these frameworks by incorporating broader economic, social, and environmental costs and benefits over a building's lifespan, aligned with standards such as Norwegian NS 3454 and UK/Canada BS ISO 15686-5:2008 (Konstantinos, 2013). TVO goes further by integrating tangible and intangible factors, including energy savings,

enhanced user comfort, and reduced facility management workloads, providing a holistic assessment of value (Azcárate-Aguerre et al., 2016).

Den Heijer's (2013) value framework contextualises these methodologies within real estate management, categorizing value into strategic, financial, functional, and energy dimensions. This aligns with den Ouden's (2012) four levels of value: user, organization, ecosystem, and society. Together, these frameworks ensure that valuation methods address the multifaceted nature of value in façade PSS, fostering informed and balanced decision-making.

SQ3: WHAT DRIVES (SEMI-) PUBLIC REAL ESTATE OWNERS TO USE FAÇADE PSS?

(Semi-)public real estate owners are motivated to adopt façade PSS by financial, operational, and sustainability benefits. A key driver is the shift from high upfront capital expenditures (CapEx) to manageable operational expenditures (OpEx). This financial restructuring frees resources for other investments, enabling faster renovations and early implementation of energy efficiency measures (Azcárate-Aguerre et al., 2016).

Advanced technologies such as Building-Integrated Photovoltaics (BiPV), automated sun-shading, and decentralised ventilation systems enhance building performance by reducing energy consumption and carbon emissions while improving indoor comfort. These features align with regulatory requirements and make buildings more attractive to users and stakeholders (Baines & Lightfoot, 2013; Azcárate-Aguerre, 2016).

User comfort and strategic flexibility further drive adoption. PSS provide healthier, more

productive environments and allow buildings to adapt to technological and organizational changes, preserving long-term asset value. Modular designs enable phased upgrades, reducing disruptions during renovations (van Ostaeyen et al., 2013).

Finally, financial innovations, such as green loans and partnerships with social banks like waterschapsbank, lower borrowing costs and increase accessibility. By integrating sustainability and aligning with organizational goals, façade PSS help real estate owners address financial constraints while enhancing building performance and meeting environmental targets.

SQ4: WHAT CHALLENGES DO (SEMI-) PUBLIC REAL ESTATE OWNERS FACE?

Adopting façade Product-Service Systems (PSS) involves challenges such as legal ambiguity, valuation issues, and stakeholder alignment. The classification of façade PSS leases—whether financial or operational—remains unclear, complicating contracts and risk allocation (Azcárate-Aguerre, 2022a). Property appraisals also fail to account for the sustainability benefits of PSS, potentially affecting borrowing capacity. While structured agreements may mitigate these impacts, the lack of standardised appraisal methods remains a barrier (Baines & Lightfoot, 2013).

Stakeholder roles add complexity. Project managers must balance budgets and timelines while navigating fragmented decision-making, while architects often prioritise aesthetics over lifecycle optimization, potentially steering projects away from sustainable solutions (Mont, 2002). Additionally, the need for interdisciplinary collaboration among finance, maintenance, and operations teams often conflicts with siloed organizational structures.

Supply chain challenges, resistance to non-traditional models, and providers' need for reserve capital further complicate implementation. Overcoming these barriers requires clear legal frameworks, updated valuation methods, and unified stakeholder efforts to align priorities and expertise (Azcarate-Aguerre, 2016).

SQ5: HOW DOES FAÇADE PSS COMPARE TO TRADITIONAL RENOVATION PROCUREMENT?

Façade PSS and traditional procurement differ significantly in cost dynamics and long-term value. Traditional procurement often appears more cost-effective based on initial Net Present Value (NPV) calculations, relying on one-time capital investments and optional maintenance contracts. However, this approach lacks incentives for proactive maintenance, leading to higher lifecycle costs and early replacements.

In contrast, façade PSS emphasise lifecycle value by integrating proactive maintenance

initially have lower NPVs due to upfront costs and risk premiums, they deliver long-term benefits like extended façade lifespan,

reduced material risks, and expedited energy savings. Providers must manage challenges such as reserve capital and delayed revenue but benefit from aligned incentives for sustainability and durability (van Ostaeyen et al., 2013).

Sensitivity analyses show PSS models are more resilient under fluctuating market conditions, particularly in scenarios with low interest rates or when benefiting from accelerated renovations. PSS also mitigate risks from material price volatility, making them a stable alternative in uncertain markets.

Though traditional procurement offers short-term cost advantages, PSS models deliver greater lifecycle benefits, aligning with circular economy goals and long-term resilience (Baines & Lightfoot, 2013; Azcarate-Aguerre, 2016). They represent a forward-looking alternative for building owners prioritizing sustainability and cost efficiency.



and circular practices. While PSS models may

FIGURE 1 WHOLE LIFE COST CALCULATION (€ IN NPV OVER 60 YEAR PERIOD)

CONCLUSION

Main question:

“HOW DO FAÇADE PRODUCT SERVICE SYSTEMS (PSS) OFFER VALUE TO (SEMI-PUBLIC) REAL ESTATE OWNERS?”

façade Product-Service Systems (PSS) deliver significant value to (semi-)public real estate owners by addressing financial constraints, operational challenges, and sustainability objectives while fostering internal organizational improvements. By shifting from large upfront capital expenditures to manageable operational costs, PSS enable owners to preserve capital reserves, enhance cash flow predictability, and undertake necessary renovations without compromising other critical investments. This financial flexibility accelerates renovation timelines, allowing buildings to achieve energy efficiency and sustainability targets earlier while improving user comfort.

Advanced technologies such as Building-Integrated Photovoltaics (BiPV), automated sun-shading, and decentralised ventilation systems reduce energy consumption, carbon emissions, and operational costs. These systems align with stringent environmental regulations and enhance the marketability of properties, making them more attractive to stakeholders who prioritise sustainability. Additionally, improved indoor conditions, including optimised ventilation, temperature control, and lighting, increase user satisfaction and productivity, reinforcing the functionality and value of public and semi-public buildings.

Façade PSS also drive internal transformation within organizations. Adopting PSS encourages a shift from traditional CapEx-

focused budgeting to a holistic approach centered on lifecycle cost management. This fosters better integration across finance, maintenance, and project management teams, enhancing collaboration and aligning operational, financial, and sustainability goals. Strategic flexibility is another advantage, as PSS allow buildings to adapt to technological advancements and changing organizational needs, preserving long-term functionality and minimizing future modification costs and disruptions.

However, several challenges remain. Legal uncertainties surrounding lease classifications, traditional property appraisal methods that overlook the benefits of PSS, and misaligned stakeholder priorities hinder adoption. Architects, for example, may prioritise aesthetics over lifecycle cost optimization, complicating project alignment. Overcoming these barriers requires clear legal frameworks, updated valuation methodologies, and cohesive collaboration among policymakers, financial institutions, architects, and service providers.

In summary, façade PSS offer a robust and comprehensive value proposition by addressing financial barriers, enabling faster renovations, improving building performance, and enhancing user satisfaction. By fostering internal organizational restructuring and strategic planning, PSS support a transition toward more sustainable and resilient building portfolios. Through collaborative efforts to address legal, financial, and operational challenges, façade PSS can unlock their full potential, playing a pivotal role in creating a circular economy and a user-centric built environment for public and semi-public real estate sectors.

RECOMMENDATIONS

Actions

TU Delft should transition from the traditional “build and let decay” approach to a planned maintenance strategy for circular façades, conducting a comprehensive audit of current practices and addressing gaps through scheduled maintenance and specialised expertise. Engaging with maintenance providers to define costs and responsibilities is essential for establishing accountability and ensuring quality service. A full portfolio analysis is recommended to assess the impact and scalability of façade PSS, with a focus on energetic performance, renovation needs, and budget alignment. Furthermore, financial analyses should evaluate how façade PSS influences borrowing capacity and solvability, ensuring investment decisions are supported by robust data. Lastly, integrating façade PSS into the university's strategic framework and aligning it with its 2040 vision will ensure long-term sustainability and flexibility.

Further Research

Future studies should address the impact of façade PSS on building appraisal values, exploring new valuation methods that consider circularity and service-based benefits. Research into alternative financing options, such as green bonds, is critical to overcoming financial barriers and aligning investor goals with sustainability objectives. The legal and contractual complexities of façade PSS also require investigation to develop standardised agreements. Comparative analyses of maintenance strategies can quantify the economic and environmental benefits of proactive approaches, while studies on the value proposition of façade PSS for housing associations can unlock new opportunities in energy-efficient retrofits. Lastly, research on the relationship between maintenance practices and façade degradation will provide data-driven insights to optimise lifecycle performance.

These recommendations provide a pathway for advancing façade PSS implementation while addressing knowledge gaps critical to its success.

01 INTRODUCTION

1. INTRODUCTION

1.1. GLOBAL RELEVANCE

1.1.1. THE PARIS AGREEMENT AND CLIMATE CHANGE

On December 12th, 196 nations convened at the Paris UN Climate Change Conference (COP21), resulting in ratifying the landmark Paris Agreement. This legally binding global accord sets an ambitious objective: to contain the rise in the global average temperature to considerably below two °C compared to pre-industrial levels and to strive towards restricting the increase to 1.5°C. To cap global warming at 1.5°C, there's an urgency for greenhouse gas emissions to peak no later than 2025 and see a decline of 43% in 2030 (UNFCCC, n.d.).

The real estate domain faces a formidable challenge in this regard. Insights from both the Carbon Risk Real Estate Monitor (CRREM) and the Global Real Estate Sustainability Benchmark (GRESB) suggest that a mere 15% of global real estate currently aligns with the 1.5°C target stipulated by the Paris Agreement (CBRE, n.d.). Currently, the world possesses over 400 billion square meters of total floor space. Astonishingly, the real estate sector contributes to around 42% of the global carbon dioxide emissions. Operational emissions from buildings constitute about 65% of this figure, while the remaining 35% emanates from construction activities (Architecture2030, n.d.; CBRE, n.d.).

Buildings in existence today contribute to a third of global emissions, approximating 11,915 MT CO₂. By 2050, this current stock of buildings is projected to make up around two-thirds of the worldwide building inventory. Both the Paris Agreement and the National Climate Agreement mandate the complete elimination of

greenhouse gas emissions from buildings by the mid-century. Moreover, aggressive targets are set for the year 2030. As a part of the Green Deal, the European Commission, in July 2021, laid out a proposal aiming for a 55% reduction in greenhouse gas emissions by 2030, benchmarked against 1990 figures. This initiative includes a 60% reduction in building-related emissions, a 14% cut in energy consumption, and an 18% decline in heating and cooling energy needs. Moreover, there's a call to amplify the renovation rates at least twofold within the coming decade. Currently, a scant 1% of buildings undergo energy-optimised renovations annually (Caloia et al., 2022) Given that buildings will see roughly 1 to 2 investment cycles from now until 2050, there's a pressing requirement to not only expedite the renovation pace but also intensify the depth of energy efficiency enhancements. Such comprehensive or "deep" retrofits are pivotal to steering the real estate sector towards a climate-resilient future. (Initiative, 2020)

1.1.2. RAW MATERIAL SHORTAGE AND A CIRCULAR ECONOMY

The built environment is pivotal for achieving the climate change targets outlined in the Paris Agreement and is essential for ensuring global resource resilience. Satterthwaite (2009) states that the primary cause of global warming is the consumption of products and services that emit greenhouse gases (GHGs) during their entire life cycle.

The construction and operational phases of the built environment significantly impact energy consumption and GHG emissions. European real estate and construction sectors contribute to over a third of the continent's waste (European Commission, 2016). In the Netherlands, statistics reveal that the real estate sector is responsible for half of the raw material usage, 40% of energy consumption, and 30% of water utilisation (Rijksoverheid, 2016)

Forecasts suggest that the global population will surge from 8 billion to around 9.7 billion by 2050, potentially reaching 10.4 billion by the mid-2080s (United Nations, 2023). This growth parallels an escalating demand for raw materials. The 20th century already witnessed a sharp increase in this demand, and projections indicate it could double by 2050, equating to an annual usage of 186 billion tons (UNEP, 2017) Such a trajectory threatens to exhaust nature's biocapacity.

The prevailing method of material consumption relies on a linear economic model. In this system, products are discarded at the end of their lifecycle, accumulating in landfills. This model is unsustainable, highlighting an urgent need for change (Leeuwen et al., 2018). Given that our economy aims for constant growth within finite resources, a new approach is essential. Enter the "circular economy", an initiative that merges economic advancement with sustainability. The circular economy's vision

is to eliminate waste by emphasising reduction, reuse, recycling, and resource recovery throughout a product's lifecycle, thereby ensuring materials have extended utility (Foundation, 2013).

The Netherlands, in its commitment to sustainability, aims to transition to a fully circular economy by 2050, with an interim target of halving the use of primary abiotic raw materials by 2030. The objective of a circular economy is to sustainably utilise renewable and readily accessible raw materials, minimising waste and inefficiencies. Recent challenges like the COVID-19 pandemic and gas shortages have exposed the vulnerabilities in our supply chains, leading to price hikes and shortages of critical materials. Embracing a circular economy can mitigate these risks while also addressing pressing global issues like climate change, environmental degradation, and biodiversity loss. However, it's worth noting that the circular real estate sector remains in its early stages (Peirani & Cochard, 2021).

1.2. PROBLEM STATEMENT

The built environment is pivotal in our pursuit of global resource resilience and addressing climate change concerns. In facing contemporary challenges like environmental decline, dwindling raw materials, energy pricing uncertainties, and the demand for affordable housing, it's paramount we re-evaluate the prevailing strategies and structures within the realms of construction and real estate.

The Circular Economy (CE) has taken centre stage in discussions about sustainable and regenerative development. A critical enabler in this shift towards a more circular economy is the ProductService System (PSS), commonly referred to as Product-as-a-Service (PaaS). This model deviates from the conventional ownership paradigm, with consumers paying for access to a product's utility rather than owning it outright. Such an approach incentivises businesses not only to design products but also to develop holistic systems of products and services tailored to specific client needs (Manzini & Vezzoli, 2003). When structured with environmental and CE indicators in mind, PSS can successfully separate value creation from resource use, driving businesses towards more regenerative and responsible practices (Fischer, Steger et al. 2012). Yet, it's imperative to note that merely adopting the PSS model doesn't automatically ensure sustainability. To achieve its full potential, PSS should be deeply rooted in circular principles, emphasising the efficient use and reuse of resources (Blüher et al., 2020; Bocken et al., 2016).

Numerous studies have delved into the creation of PSS tailored for use in the built environment. One notable application of PSS pertains to building façades. The building envelope, along with integrated decentralised building services, plays a pivotal role in determining energy efficiency and ensuring user comfort Azcarate-Aguerre (2023). Moreover, when you combine

the envelope with service functions, the building exterior can contribute to nearly 40% of a new building's initial expenses (Azcarate-Aguerre et al., 2022). In situations involving comprehensive building retrofit projects, where the site, structure, and other architectural systems are repurposed, a façade featuring integrated building services can constitute more than 90% of the project's upfront costs (Azcarate-Aguerre et al., 2022; Dall'O et al., 2013).

Earlier studies have examined the challenges associated with scaling up the implementation of façade product service systems. This exploration was conducted through two pilot projects at TU Delft. The initial project centred on technological readiness, took place at the EWI building in 2017. The subsequent project, which delved into systemic challenges and potential solutions, was conducted on the CiTG East Facade in 2019 (FaaS 1.0) (Azcarate-Aguerre, 2023). Insights gained from both the EWI and CiTG 1.0 FaaS pilot ventures shed light on the persistent hurdles the industry encounters in establishing a comprehensive FaaS contract. Drawing from Azcarate-Aguerre (2023), there are four principal conclusions which resonate with the primary barriers impeding the widespread transition to a circular economy within the construction sector. These challenges encompass cultural, regulatory, financial, and technical aspects, as delineated by various scholars (de Jesus & Mendonça, 2018; Hart et al., 2019; Hobbs & Adams, 2017; Kirchherr et al., 2018).

The technical implementation of an integrated service façade is readily explored and is proven to be feasible. However, “A lack of valuation standards which fairly consider softer values and “externalities” such as user comfort, energy performance, resource depletion, carbon emissions and other environmental impacts, material circularity, or managerial streamlining, negates an equitable financial foundation on

which PSS alternatives can be built”(Azcarate-Aguerre, 2023).

While many studies have delved into the financial obstacles surrounding circular real estate,(Durmisevic, 2016; Hobbs & Adams, 2017; Rosa et al., 2019) there's a need to further probe into the financial challenges associated with PSS in the real estate sector. The adoption of circularity mandates the implementation of novel business models. Practices like energy efficiency, commonly perceived as additional short-term capital expenses for firms and their backers, are reframed by the Circular Economy model (Azcarate-Aguerre et al., 2022; Figge & Hahn, 2005).

Adopting a circular model for component and material use can mitigate manufacturing expenses and reduce susceptibility to global raw material market fluctuations. Transitioning the focus from product sales to service provision can offer more consistent revenue streams across the value chain, shielding stakeholders from unpredictable shifts in real estate market markets (Alix & Vallespir, 2009; Azcarate-Aguerre et al., 2022). These long-term orientations demand innovative business models accompanied by the right revenue models. Yet, capturing the essence of circular business models in financial and legal terms remains largely unexplored. Recognising and appraising these models is paramount for transitioning to a circular economy (Rosa et al., 2019). Effectively, a comprehensive methodology to compare linear and circular contracting processes in terms of their Total Cost of Ownership is still necessary. The TCO needs to be balanced against the Total Value of Ownership (TVO) when managing a building portfolio (Azcarate-Aguerre, 2023).

Besides the absence of established valuation standards, there's the inherent "circular risk" – the risk stemming from adopting circular practices – which investors often deem

significant. This perception arises because circularity demands a transformative approach to business operations. To retain control over raw materials and optimise value, stakeholders within supply chains must foster collaboration, resulting in a realignment of incentives (Circle Economy et al., 2016; Fischer & Achterberg, 2016) In reality, circular business models can be challenging to scale and finance. This is partly attributed to an uneven landscape where environmental degradation and resource exploitation aren't adequately taxed. Additionally, the immature market for reclaiming and reusing materials hinders the inclusion of future residual values in financial models. There's also discord between the longevity of circular business models and the short-term nature of financial products and risk assessments. Underlying reporting rules, especially those concerning balance sheet expansion, pose significant barriers. Financing often centres on tangible assets, while the value of circular ventures typically is a mix of assets, services, collaborative efforts, contractual agreements, and projected revenue streams.

A creative solution for products like a Façade PSS could involve combining circular projects into a singular investment fund. Instead of backing individual projects, financial institutions might invest in or hold stakes in this collective entity. Such an approach would distribute risks across various stakeholders, mirroring practices in Project Finance (PF), and would sidestep banks' reluctance to sanction smaller loans (Achterberg & Van Tilburg, 2016). However, research on this project portfolio financing approach for façade PSS, especially in the context of previously mentioned valuation standards expressed as TVO, remains a relatively uncharted domain.

1.3. SCIENTIFIC RELEVANCE

As of now, two pilot projects at TU Delft have taken place, exploring the barriers to upscaled implementation of façade product service systems: The first focusing on technological readiness on the EWI building in 2017, and the second one focusing on systemic barriers and solutions, on the CiTG East Facade in 2019 (FaaS 1.0) (Azcárate-Aguerre, 2023). In addition to this research, a third pilot project is currently being developed: Leasegevel 2.0 I (integrated) Facades-as-a-Service.

The project builds on the outcomes of the earlier projects, which were developed in collaboration with TU Delft (CRE), TUD Faculty of Architecture & the Built Environment (AE+T & MBE departments), and commercial façade builder Alkondor Hengelo B.V. at the head of a façade-integrated system and component supplier consortium. The main research objective is to demonstrate and validate how can a full circular Facade-as-a-Service proposition be implemented in a scalable way in the existing built environment and under current market conditions, starting with the West façade of the Civil Engineering building on the TU Delft campus as a case study. However, at the moment of publication, the third installation of the research project has been put on hold.

Therefore, this research revisits the drivers and barriers encountered leading up to the Leasegevel 2.0 project. While simultaneously contributing to the validation of the valuation methodology of the Façade as a Service concept in comparison to conventional (linear) alternatives.

The Leasegevel 2.0 project could unlock an entirely new sector in energy- and resource-efficient building envelope retrofits and motivate better-performing decisions also on new projects. Success in the early phases of a case-study building would help develop confidence in

this sector and kickstart an upscaled FaaS investment initiative.

1.4. RESEARCH QUESTIONS

As previously mentioned, there is a strong desire in the Netherlands to transition to a sustainable built environment and realise a circular economy by 2050. Business models centred around Façade PSS offer immense promise in furthering this goal. Yet, the adaptation of such a concept is not common business practice, even for a best-case scenario such as an university living lab. Therefore, the primary research question is:

“HOW DO FAÇADE PRODUCT SERVICE SYSTEMS (PSS) OFFER VALUE TO SEMI-PUBLIC REAL ESTATE OWNERS”

In this study, "value" is characterised as the "relative worth, worth, utility, or importance" concerning rate or scale in usefulness, importance, or general, as defined by Merriam-Webster (2024).

The value to be determined is that of Façade PSS from a consumer perspective in the context of the Total Value of Ownership. Concurrently, it is also the value of a Façade PSS from a provider perspective in the context of product service offering that needs to be defined. To answer the main research question, the following sub-questions must be answered:

SQ1: What are Façade Product Service Systems (PSS)?

SQ2: What are the current methodologies for valuing façade PSS?

SQ3: What are the drivers for semi-public real estate owners to use façade PSS?

SQ4: What challenges do semi-public real estate owners face when using façade PSS?

SQ5: How does the use of façade PSS compare to traditional façade renovation procurement?

2. METHODOLOGY

2.1. RESEARCH DESIGN

This study employs a mixed-method approach, blending qualitative and quantitative methods for a detailed understanding of the topic of Façade Product-Service System (PSS) valuation. This approach, as noted by Creswell & Creswell (2017), allows for nuanced analysis through both deductive and inductive reasoning, enhancing the research's robustness (Bryman, 2016). The research begins with an extensive literature review, setting a theoretical foundation. The empirical phase uses a single-case study method, effective in examining real-world issues in specific contexts (Yin, 2018), and semi-structured interviews for in-depth qualitative data collection (DiCicco-Bloom & Crabtree, 2006). The research synthesis combines a Monte Carlo simulation for financial modelling (Glasserman, 2003). This mixed-method strategy ensures a comprehensive exploration of Façade PSS valuation.

incorporation of spontaneous interactions as valuable data sources. By engaging directly with participants in their environments, nuanced perspectives are captured, enhancing the depth of the research. This approach not only yields practical, context-rich knowledge but also empowers participants by involving them in the research process. The iterative nature of action research ensures that these informal conversations and observations are effectively integrated, thereby enriching the study's relevance and impact (Kemmis, 1988).

2.2. ACTION RESEARCH

In this research project, alongside the planned research methods, action research will be implemented. This methodology is particularly relevant due to the researcher's engagement in off-the-record conversations and attendance at meetings within the parallel research project or with external stakeholders, which may not be pre-planned. These interactions offer critical insights and real-time data essential for a comprehensive understanding of the context.

Action research is a participatory and reflective methodology ideal for such dynamic settings. It emphasises collaborative problem-solving and improvement of practices through cycles of planning, action, observation, and reflection. The adaptability of action research allows the

2.3. THEORETICAL RESEARCH

The theoretical Research delves into a detailed literature review, a vital element in academic research. This review aims to methodically collect, critically evaluate, and integrate existing knowledge about two primary subjects: Façade Product-Service System (PSS) and Value. The review process, critical for establishing a strong research foundation, is divided into three stages — defining, collecting, and synthesising — and also focuses on identifying gaps in the current literature.

2.3.1. DEFINING

The "Defining" stage is the first part of the literature review. Here, essential concepts and terminology related to Façade PSS are clarified. The research includes a thorough exploration of Façade PSS, understanding its significance in creating economically and environmentally sustainable building solutions, and examining its various dimensions and characteristics as described in the literature. This phase is not just about gathering existing knowledge but also about critically assessing and interpreting it, aiming to establish a clear, consistent conceptual framework for the study.

2.3.2. COLLECTING

The "Collecting" phase concentrates on identifying and examining current valuation methods and metrics relevant to Façade PSS. This stage is crucial for understanding the quantitative assessment of these themes in past studies and practice, setting the groundwork for developing a comprehensive framework. The research involves gathering different valuation techniques and methodologies and analysing their contribution to the economic viability and sustainability of building solutions in the context of PSS projects. This phase goes beyond merely aggregating existing knowledge and

critically evaluating and contextualising this information within the research framework.

2.3.3. SYNTHESISING

The "Synthesizing" part is the final stage of the literature review. It aims to integrate the methods and metrics identified for Façade PSS and Financeability into a comprehensive valuation framework, the Total Value of Use (TVU) model. This model is designed to provide a holistic approach to valuation, encompassing both qualitative and quantitative aspects, and will be a critical tool for evaluating and comparing different Façade PSS solutions. The synthesis involves summarising findings from the defining and collecting phases and critically analysing how these elements can be combined to create a robust valuation framework. This phase is about visualising a new tool that addresses the complexities of valuation in the context of Façade PSS, leading to the development of a comprehensive perspective on valuation. The TVU model, as a result, is expected to provide a robust solution for assessing the economic viability and sustainability of building projects, marking the culmination of the literature review process.

2.4. EMPIRICAL RESEARCH

In the empirical research phase of this study, a single-case study complemented by semi-structured interviews will be used, all guided by the developed Theoretical Framework or the "TVU-model." The single-case study method focuses on comparing theoretical insights from the TVU model with real-world practices, identifying similarities and differences to deepen understanding of the added value of a Façade PSS. This involves document and data analysis within the case. Semi-structured interviews will gather stakeholder perspectives on the expected value and the current barriers. Findings from these methods will inform the refinement of the TVU model.

2.4.1. SINGLE-CASE STUDY DESIGN

This research will implement a single-case study to gain a deeper understanding of complexity and de practical drivers and barriers that occur in a façade PSS. This case study is the Leasegevel 2.0 I (integrated) Facades-as-a-Service project at the TU Delft. The reasoning for a single case study, contrary to a multiple-case study design, is based on two rationales from Yin (2003): the unique case and the longitudinal case. Firstly, the Leasegevel 2.0, more commonly referred to as the CiTG Westfacade, is exemplary as it is the first of its kind. Because of the complexity and the intricate governance structure, there are no comparable PSS offerings suitable for comparison at the time of writing. Secondly, this research considers all earlier phase part of the same project at different points in time. Both the EWI building in 2017 and the CiTG East Facade in 2019 (FaaS 1.0), although unique in their product delivery, are part of an ongoing and developing stakeholder network. Because of this stakeholder complexity, the case study will be an embedded one instead of holistically. Taking multiple perspectives into consideration.

2.4.2. SEMI-STRUCTURED INTERVIEWS / EXPERT INTERVIEWS

In the empirical phase, semi-structured interviews, conducted alongside the case study, are key for gathering in-depth qualitative data. These interviews are informed by the developed framework, aiming to bridge the gap between objective knowledge and subjective insights (McIntosh & Morse, 2015). An interview protocol with open-ended questions allows flexibility for interviewees to express views and for researchers to delve deeper, a method effective in revealing insights not captured by structured surveys (DiCicco-Bloom & Crabtree, 2006). The interviews will explore roles, influences, barriers, and drivers as experienced by key stakeholders in relation to the façade PSS concept. This process aims to enrich and validate the TVU model, identifying patterns to lend concreteness to the findings. The focus is on engaging a purposive sample of 'informed individuals', essential for deep understanding in niche areas like Façade PSS (Deitz, 1987). Given the concept's novelty, criteria for 'informed individuals' are specifically defined. Following Pendergast and Marr (1994), the sample size aims for eight to twelve participants to optimise group input without redundancy. The study will include interviewees from various relevant stakeholder perspectives. The interviewees will be selected through snowball sampling.

2.5. FINANCIAL MODEL

A comprehensive financial model will be made to provide meaning full insight in the financial implications of the CiTG case. It encompasses a TVO/TVU calculation from the client perspective as well as a 3-statement model and a DCF model from the provider perspective.

Finally, a dynamic sensitivity analysis will be made for the TVO model through a Monte Carlo simulation. This technique is employed to explore the range of possible outcomes in the TVO model by varying input parameters stochastically. Monte Carlo Simulation allows for the assessment of the impact of uncertainty and variability in key variables on the final valuation outcomes. By running numerous simulations with random inputs within specified ranges, the research can generate a distribution of possible outcomes. This approach is particularly useful in understanding and quantifying the risks and uncertainties inherent in the financial and operational aspects of Product Service Systems. The findings from the Monte Carlo Simulation will be critical in fine-tuning the TVO model, ensuring its applicability and reliability in diverse and uncertain real-world scenarios.

2.6. DATA COLLECTION AND ANALYSIS

For the case study, all relevant documents will be acquired from involved stakeholders, more specifically, a representative from the façade service provider and a former researcher on the project. Both are well-connected within the project and have or can provide access to relevant documents, information and contacts for the expert interviews. Findings from these will be gathered and consolidated into the report. This insight will serve to enhance the framework. The report will segregate the analysis of the case study as follows:

Introduction: An overview of the Leasegevel 2.0 case, highlighting key information essential for interpreting the subsequent findings.

Findings: A detailed account will be made of the values considered, discussed and applied; the roles and influences of the individuals involved will be mapped, and the decisions and factors influencing implementation will be highlighted.

The expert interview transcripts will undergo thematic analysis, involving the coding of the recorded transcripts and associating them with distinct themes. The purpose of this analysis of the former is to corroborate the actual perceived and expected drivers and barriers.

2.7. DATA MANAGEMENT AND ETHICAL CONSIDERATIONS

This study will look into ongoing negotiations and discussions between various stakeholders involved in the case study. Furthermore, sensitive (financial) data is shared with the researcher. For this reason, the researcher has chosen to remain impartial and not position themselves with any external or market party. By harbouring academic integrity, any bias can be

marginalised and stimulate transparent communication.

Participant data is essential for developing practical knowledge in social research, necessitating a focus on ethics. The researcher's responsibility is to ethically manage the impact of their work. Details of the data management plan are in Appendix X: Data Management Plan. The study involves various data types:

- Analysis of literature and documents
- Documents and confidential and sensitive(financial) data from the case study
- Personal details of interviewees from the case study and expert panels
- Notes, recordings, and transcripts from semi-structured interviews
- Summaries, notes, and recordings from expert panels

Given the involvement of human subjects in interviews, consent forms are required before collecting notes, recordings, and transcripts. The researcher owns all interview data, including notes, recordings, transcripts, and coding. This encompasses responsibility for data processing, storage, and dissemination during and post-research. Data security is ensured by storing it on TU Delft's drive, with the final report being accessible on the TU Delft repository.

Participant well-being is paramount, ensuring no harm comes from their participation. Clear information about the research objectives is provided beforehand. Participants can refuse to answer questions that infringe upon their privacy or ethical values. To maintain ethical integrity, participant identities are obscured in the final documents. Participants will be informed about their representation in the thesis before publication.

2.8. RESEARCH OUTPUT

2.8.1. DISSEMINATION AND AUDIENCES

This research will be disseminated to all the stakeholders involved in the Leasegevel 2.0 pilot project. Additionally, the research can be used by various interested parties, varying from PSS providers, (Semi-)Public Institutions, Developers and investors and people concerned with the circular economy in general.

2.8.2. PERSONAL STUDY TARGETS

The topic of this research was derived from a personal interest. After reading the book *Material Matters* by Thomas Rau, the idea of product-service systems became one that would intrigue me. After much internal thought about the matter and some discussion with peers, the concept bloomed into an ambition. Why could the concept, implemented in lights and carpets, not be brought to a bigger stage: Facades? Initially, the idea came to mind when thinking about how impoverishment and degradation in residential buildings could be mitigated. However, the idea had faded as many peers and seniors were harsh enough to shoot it down. The idea got stored away, but when the time came to select a topic for this thesis, it came right back. Through some quick searches, it became apparent that not only was the concept being tried and tested, but it was also in my backyard at the TU Delft. With an ever-present ambition to enlighten me about any new technological advancements, this thesis was founded. Through this research, I hope to learn more about the concept of product-service systems, valuation methods and financial models on both an educational and personal level.

02 THEORETICAL FRAMEWORK

The following section aims to create a broader conceptual understanding of the research topic. It sets out to answer the first two sub-questions:

SQ1: What are Façade Product Service Systems (PSS)?

SQ2: What are the current methodologies for valuing façade PSS?

1. PRODUCT SERVICE SYSTEMS (PSS)

1.1. DEFINING PSS

A Product-Service System (PSS) is an innovative approach that combines tangible products and intangible services to fulfil specific customer needs effectively (Tukker, 2004). The concept was described as a system where traditional, material-intensive product usage is replaced by dematerialised services. This shift often involves changes in ownership structures, as noted by Mont in 2002. The as a service model provides various levels of retained ownership instead of transferring it to the client, as is customary in traditional procurement models. This aspect of PSS is crucial because it allows for the decoupling of environmental pressure from economic growth, a potential highlighted by Goedkoop et al. in 1999.

Expanding on this idea, Baines et al. in 2007 defined a PSS as an integrated product and service offering that delivers value in use. The PSS framework offers a significant opportunity to separate economic success from material consumption, thereby reducing the environmental impact of economic activities.

The initial reasoning for implementing this business model is, therefore, twofold. Firstly, the economic benefits for the client and provider. A PSS business model allows firms to create new sources of added value and competitiveness. The servitisation approach enables companies to explore new revenue streams, enhance customer relationships with better provision of their needs, and shift service from a cost to a value creator while often promoting scalability (Baines et al., 2007).

This retained ownership enables the secondary benefit of servitisation, which is the dematerialisation of industrial practices. This is by naturally shifting the core business incentives

of suppliers and consumers away from resource consumption and towards revenue models which reward efficient and regenerative use of human, material, and energetic resources (Baines & Lightfoot, 2013; Azcárate-Aguerre, 2022a).

In general, PSS are likely to give more attention to the use phase of the product's life cycle (consumer stage) than current product systems do since the provider retains ownership of the service product (Mont, 2002). The logic behind this is based on leveraging the knowledge of designers and manufacturers to increase value output while simultaneously decreasing material and other costs as inputs (Baines et al. 2007).

In the present economy, due to current incentives, producers are typically rewarded by reducing costs via mass production, by providing standard non-exceptional quality, and by creating products with relatively short lifespans (Mont, 2002). Producers make a profit when consumers rapidly purchase and thus are disincentivised from making long-lasting products. The longer the lifespan of their product, the less of the product they can sell, and therefore the less profit they can make. Once a product has been purchased, it is the consumer's obligation to maintain the product and responsibly dispose of it at its end of life.

While on the other hand, PSS models are in close relation to circular business models. This is by naturally shifting the core business incentives of suppliers and consumers away from resource consumption and towards revenue models which reward efficient and regenerative use of human, material, and energetic resources (Tim Baines & Howard Lightfoot, 2013; Azcárate-Aguerre, 2022a). This change in incentive structure enables the secondary benefit of PSS: sustainability. As Mont (2002) states, a predominant goal of PSS should be to mitigate the environmental impact

of consumption. Achieving this goal can be done through several strategies, such as:

- closing material cycles;
- reducing consumption through alternative scenarios of product use;
- increasing overall resource productivity and dematerialisation of PSS;
- Provide system solutions seeking perfection in integrating system elements along with improving the resource and functional efficiency of each element.

While the earlier definitions by Tukker (2004) and Baines et al. (2007) emphasise the consumer, they do not explicitly highlight the potential environmental benefits of PSS. Therefore, Munten et al. (2021) recently incorporated consumer needs, environmental impact, and the corporate perspective into their definition. This provides a more holistic view of PSS, emphasising the importance of consumers and the environment.

“A PSS is a business model that offers sets of products and services that together meet consumers’ needs in such a way that they not only satisfy consumers but also provide service-based competitive advantages to firms while aiming at decreasing the negative environmental impacts associated with

overproduction and overconsumption, relative to traditional models.” (Munten et al., 2021).

1.2. CLASSIFYING PSS

As it becomes apparent, the definition has evolved and developed. This is partly due to PSS not being a binary concept but rather on a spectrum. The ratio of product/service has been depicted by Tukker (2004) as a sliding scale. He introduces a classification system for the various types of service systems based on the most common distinction categories (Fig. 1). The model he proposes accounts for varying extends of product (traditional procurement) to Service (delivery of performance), grouped into three main categories; product-oriented, use-oriented, and result-oriented PSS. This trichotomy encapsulates the eight types of PSS he differentiated.

Although Tukker (2004) identifies a major shortcoming in his typology, going from the first to the last of these eight types of PSS, the reliance on the product as the core component of the PSS decreases, and the need of a client is formulated in more abstract terms. Every time, the provider has a little more freedom in fulfilling the true final need of the client. However, abstract demands are often difficult to translate into concrete (quality performance) indicators, which makes it difficult for the providers to determine what they have to supply and difficult

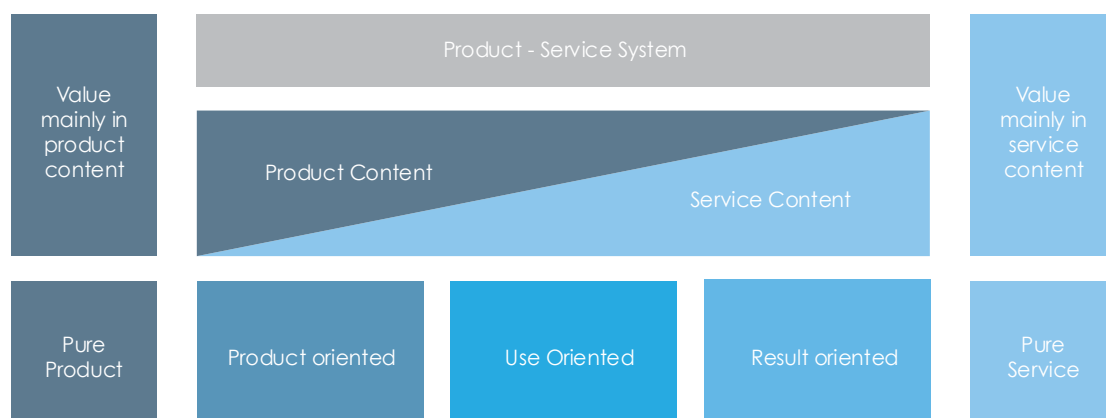


Figure 2 Categories of PSS adapted from (Tukker, 2004)

for the clients to know whether they have got what they asked for (Tukker 2004).

Furthering this reasoning, the classical PSS typology is subject to three main problems that prevent it from capturing the multiplicity and nuanced differences that exist between different PSS options in practice (Ostaeyen et al., 2013). The logic for these shortcomings is to be found in the choice of the distinguishing features between PSS types that emphasise the allocation of property rights and in the fact that the notion of ‘function’ is not systematically treated in the available PSS literature,

although orientation toward the provision of ‘function’ is an essential characteristic of a PSS (Mont, 2002; Tukker & Tischner, 2006). Because the prevailing typology is not sufficiently refined to distinguish between different types of result-oriented PSS. The result-oriented PSS type is claimed to ‘directly fulfil customer needs’ or to ‘provide functional results’, although both concepts (needs and functions) are quite problematic to express unambiguously in concrete terms (Tukker, 2004).

Being able to classify a PSS and its purpose is inherently necessary to assess the model, determining its worth by identifying the value proposition offered. Van Ostayen et al. (2013) state that a PSS and its business model can be represented by first specifying which product and service elements it includes (i.e. the PSS elements). Followed by how these elements within the PSS generate income for the PSS provider (i.e. the revenue mechanisms). And lastly, how these elements are integrated (i.e. the level of integration). They categorise the revenue models as follows: input-based (IB), availability-based (AB), usage-based (UB), and performance-based (PB). These four revenue models are comparable with the “Product, Use and Result” categories proposed by Tukker (2004). However, there is a main distinction with the last category. Here, the PB is subdivided into three types: solution-oriented (SO), effect-oriented (EO) and demand fulfillment-oriented (DO). The new revenue streams can be applied to each service offering of the PSS individually, and the level of integration indicates which services are grouped within one offering. Therefore, allowing separate revenue models within the same PSS offering is shown below.

Type	Payment allocation >50% PRODUCT >50% SERVICE			
	1. INPUT BASED	2. AVAILABILITY BASED	3. USAGE BASED	4. PERFORMANCE BASED
Payment allocation	Product related payments	Service related payments		
Payment Structure	At moment of purchase and at completion of service	When component is available	When component is Used	When performance criteria is met
Utility accessed	Purchased	Commonly leased		
Owner of product	Building owner	PSS provider / Bank		
Maintenance and operator	PSS Provider / Building Owner	PSS Provider		

Figure 3 PSS contextual framework adapted from (Mont, 2004; Parker, 2023)

1.3. CONTEXT OF PSS

The improved taxonomy by Ostaeyen et al. (2013) better encapsulates the wide and unique variety of service offerings available within the realm of PSS. However, it is still lacking context, as is highlighted by the extensive systemic review by Annarelli et al. (2016). They identified that the majority of PSS frameworks are provider-client-centric, with some of them also considering the environmental implications. Yet only one framework provides a more holistic view, incorporating also networks and infrastructures and social aspects and partnerships.

This framework by Mont (2004) offers a way to identify all value created, delivered and captured in its wider context. The growing complexity and magnitude of PSS offerings require a more holistic approach. Additionally, some of the main barriers to the implementation of PSS models have been identified as a cultural shift necessary by Goedkoop et al. (1999). This, in combination with Inherent capital and investment needs (Mont, 2002).

Requires more stakeholder involvement and, thus, a need for value identification beyond the demand-supply metric. Mont (2002), therefore, places the PSS elements within its cultural

context, consisting of the Feasibility- and the Institutional framework.

PSS Elemental Framework focuses on the core components of a PSS: the tangible product, the accompanying services, the necessary infrastructure, and the actor-network, which includes all collaborative stakeholders responsible for delivering the PSS. This foundational understanding is expanded by the PSS Feasibility Framework, which examines the drivers for adopting PSS solutions. It highlights the importance of addressing user needs and satisfaction while also aiming to minimise environmental impact and ensure business viability through value creation shared among stakeholders.

Finally, the PSS Institutional Framework considers the broader context in which PSS operates, analysing cognitive, normative, and regulatory settings. Cognitive settings involve the processes for information gathering and decision-making, normative settings address societal attitudes and behaviours towards PSS, and regulatory settings reflect the legal frameworks shaping the PSS market. Together, these frameworks provide a holistic perspective on the design, feasibility, and institutional environment for successful PSS implementation.

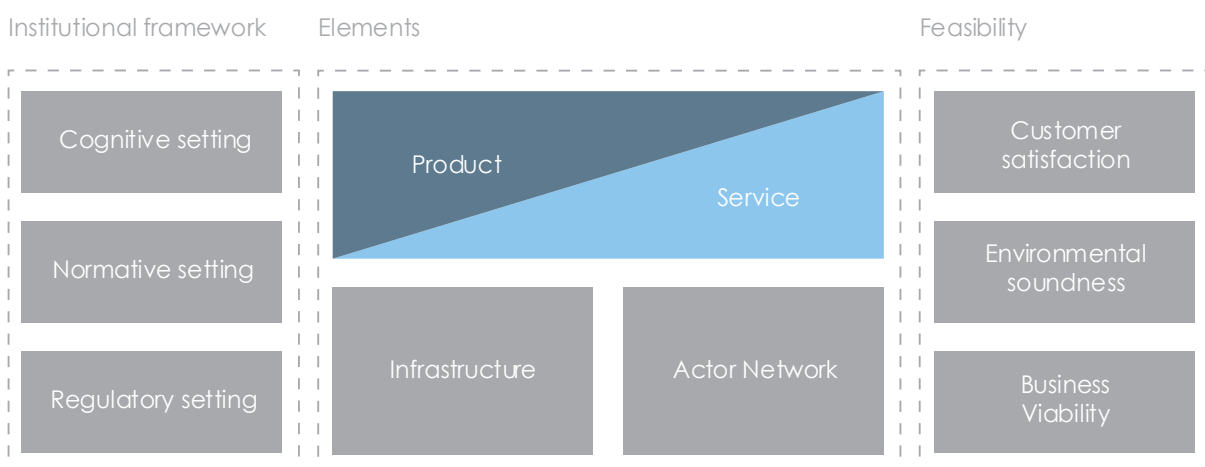


Figure 4 PSS contextual framework adapted from (Mont, 2004; Parker, 2023)

1.4. FAÇADE PRODUCT SERVICE SYSTEMS

To assess what façade product service systems are, the next section will use the framework of Mont (2002) to discuss the context of what a façade PSS proposition can entail at this moment.

PRODUCT:

While there is no single solution associated with the façade PSS concept, integrated modular curtain wall façades provide ample opportunity for the implementation of such a concept. Integrated Façades are advanced architectural components where major service and climate management systems of a building are embedded in the envelope's modular design. This approach is utilised in curtain wall structures and independent modular window units. Typically, a broad frame around the glass façade incorporates various technical systems like heating, cooling, ventilation, and energy management, along with media projection, electrical and water services, and sensors for monitoring performance. These façades represent a blend of functionality and design, integrating essential building services into the structural exterior. (Azcarate-Aguerre et al., 2014).

Azcarate-Aguerre (2015) highlights four levels of integrated functionality possible in a façade: basic functions, energetic functions, supply functions and advanced/ profit-generating functions. Traditional façades perform several important functions, such as protection against climate and heat, noise and pollutants, ventilation, humidity control, fire safety and others. However, combining the building envelope and HVAC systems into a single PSS offering for thermal comfort results in measurable performance of protection against climate and heat (van Ostaeyen, 2013).

Multi-functional integrated façades are advancing towards more decentralised solutions, significantly enhancing the role of a building's outer shell. These façades can encompass nearly all systems crucial for indoor comfort, adapting to limitations like spatial layout, design, and user interaction within existing buildings. As a result, they offer an alternative to centralised systems, covering aspects like ventilation, temperature control, and energy management. Their scope and efficiency in providing these services are continually evolving, demonstrating their potential in modern architectural designs. (Klein, 2013; Azcarate-Aguerre et al., 2016).

SERVICE:

In a façade PSS offering, there are two types of services: servicing and product-related services. Servicing is all the material input and labour required after the initial production. This includes management, monitoring, maintenance, repairs, overhaul and replacement (Ostaeyen et al. 2013). These can be categorised into two groups: planned and unplanned. Then additionally, there are product-related services. These are inherently linked to the product specifications. The level of integrated systems in the façade defines what services it is capable of providing. Although project dependant, these can also be categorised as economic, technical and functional. The economic subset relates to benefits associated with the economic viability of the client, such as revenue and expenditures. The technical subset is the most related to the integrated façade system and can be aligned with meeting performance requirements for climate and energy consumption. The functional subset is related to the user, here, user performance and comfort are more substantial, and can the aesthetic preferences be accounted for (Ostaeyen et al., 2013; Thomsen & Straub, 2018).

INFRASTRUCTURE:

The infrastructure required for a façade PSS can be defined, although dependent on the specific service offering, as the following elements. First, the project site and the site accessibility. It provides crucial information required for determining the exchange value of the PSS offering. As climate and environment influence the deterioration, accessibility determines the expenditures and speed of operations involved with maintenance and replacements. Secondly, the building structure and suspension points serve as the direct infrastructure of a PSS. Additionally, any utility connections, such as electrical and data cabling, are determinants for the extent or possibility of integrated (smart) systems. Regardless of the PSS offering, connections with the building's overall utility network need to be integrated or demarcated. Lastly, the PSS offering should be compliant with the building's fire safety codes, like fire resistance and exit routings.

ACTOR-NETWORK:

With a façade PSS, there are multiple essential stakeholders. The manufacturer, the service provider, the customer/user and the financier. While the producer and the service provider may be the same party, they do not have to be. This is also true for the client and user; these can be separate entities. Finally, there is the owner. The (economic) ownership of the product lies (depending on the underlying contract structure) with the producer, with the service provider, or with a separately created for this purpose entity, such as a Special Purpose Vehicle (CCA, 2020).

Provider:

The manufacturer of the façade can decide to form a consortium with other façade builders or organisations from its supply chain. Through such a consortium, a Special Purpose Vehicle (SPV) can be instigated to own and manage the leased façade. The intention of such a Façade Service Company (FSC) can be to provide joint

and several guarantees, lowering the risk for financiers. Alternatively, back-to-back contracts can be substantiated. This means that responsibilities and risks are shared contractually (rather than with guarantees) with the underlying parties. Where normally collateral is obtained from mortgage rights, the collateral in this structure is taken from subscription rights, a demurrage right and a removal right.

Client

The real estate demand side is diverse, encompassing various stakeholders like private, commercial, corporate, and public entities, each with unique economic traits, strategic goals, and value systems. These stakeholders can be categorised by owners, users and owner-users. When there is an intervention or transaction, they become clients that pay for products and/or services. As owners of buildings, clients will focus on residual value, life cycle costs, and return on investment. As users of these buildings, clients will concentrate on how their organisational performance is affected by the building. The blending of owner and user perspectives in one client necessitates considering strategic, functional, financial, and physical aspects together (den Heijer in 2011; Azcarate-Aguerre, 2017).

Furthermore, the type of client is detrimental to the client-supplier relationship. With PSS, the focus shifts to long-term customer relationships, demanding a higher level of mutual trust. Façade PSS are still in the pioneering phase and has inherently high initial capital expenditure for the service provider. Therefore, financiers include risk premiums (CCA, 2020). For this reason, the willingness of the provider to collaborate with clients who's economic and incentives are not in long-term alignment is low. In commercial real estate, for example, different organisations often handle various life-cycle stages, each with varying timelines and potentially conflicting financial interests

(Azcarate-Aguerre, 2017). This holds especially true in back-to-back contracts, as commercial parties are highly susceptible to market conditions and with financial crises, the guarantee of the underlying contracts dissolves.

Financier

An investor's main aim is to create revenue against acceptable risks (Van Driel & Van Zuijlen, 2016). However, what this acceptable risk is is dependable on the type of investor and their investment style. Investment style classifications, recognised by INREV (2012) and other institutions, group investments based on similar risk/return profiles into categories like core, core plus, value-added, and opportunistic. Because the PSS offerings decouple the façade from the building structure, a high risk is associated with it. Therefore, an equilibrium needs to be found between business model, risk profile and financing. In the façade PSS context, options in which a portion of the equity is raised, either from the client side or from an investment fund, have been considered. It also needs to be taken into consideration that the underlying façade technology is already proven, and high financing costs make the business case unappealing. A bank loan, therefore, seems to be the best form of financing (CCA, 2020).

However, because there are no established historical records or risk assessment strategies for financing façade PSS projects, financially robust entities like publicly-funded institutions as clients could be perfect for pioneering the concept. Their consistent operations and strong credit ratings offer additional assurance for service fee payments (Azcarate-Aguerre, 2018). This allows for a "Best-case scenario" analysis of the concept, should it prove unsuccessful in these conditions, it is highly improbable that it would succeed in a context beyond research and development.

Emerging collaborative models introduce new problems in multi-actor dynamics and create interconnectedness in intricate service systems (Sangiorgi, Patricio, and Fisk, 2017). Likewise, the complexity of value propositions increases when multiple companies contribute resources to develop and market a product from beginning to end (Appleyard & Chesbrough, 2017). When organisations depend on each other, it becomes essential to establish an ecosystem-wide value proposition that integrates the individual contributions of various participants.

This intricate value proposition introduces new challenges in reconfiguring the value network, where value propositions are interwoven, as are the value exchanges among various organisations (Vink, 2021). Azcarate-Aguerre (2018) proposes the following stakeholder model. This approach takes into account the core actions of various stakeholders, their continuous interactions, and sources of sustained social and corporate value beyond just financial aspects.

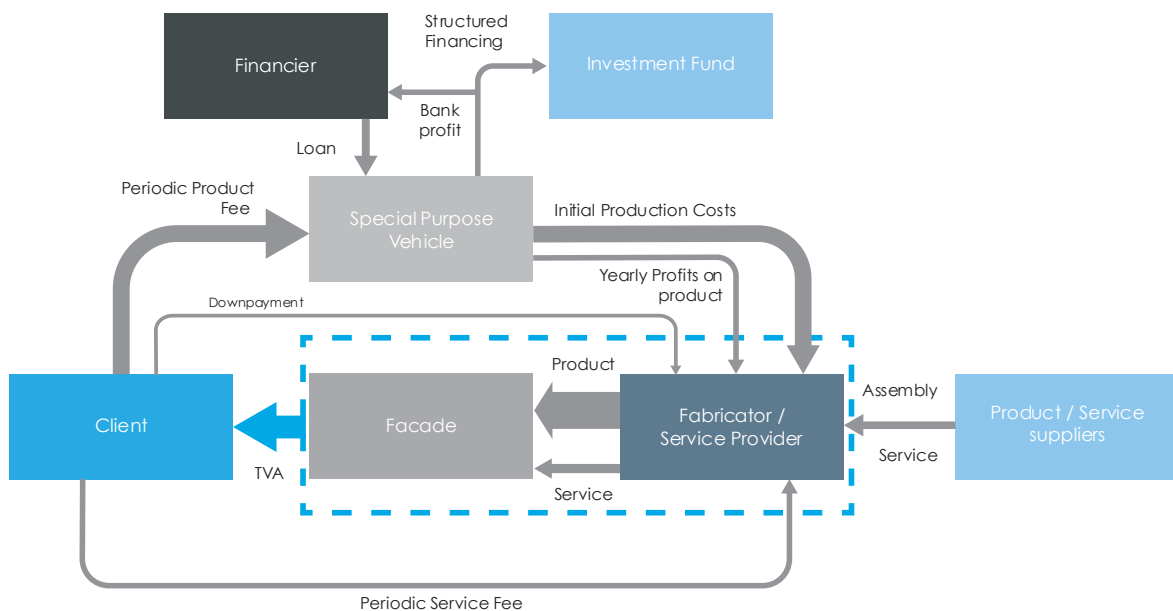


Figure 5 Stakeholder network adapted form (Azcarate-Aguerre, 2018)

CLIENT DEMAND (OWNER):

As mentioned in the stakeholder network, the client and user are not necessarily the same and therefore, their demands vary. However, user demands are part of the strategic portfolio management KPI's in the built environment (den Heijer, 2011). Because of this, the demands of the owner and the user need to be aligned. The economic characteristics, strategic priorities, and value hierarchies of these various stakeholders can be very different, though.

Where the (semi-)public clients often have non-profit, socially-oriented strategic goals, resulting in a long-term interest in the performance of their portfolio (den Heijer, 2011), where the commercial real estate sector client consider the development, ownership, management, and exploitation of a property means to an end with the final purpose of generating profit. In the table below.

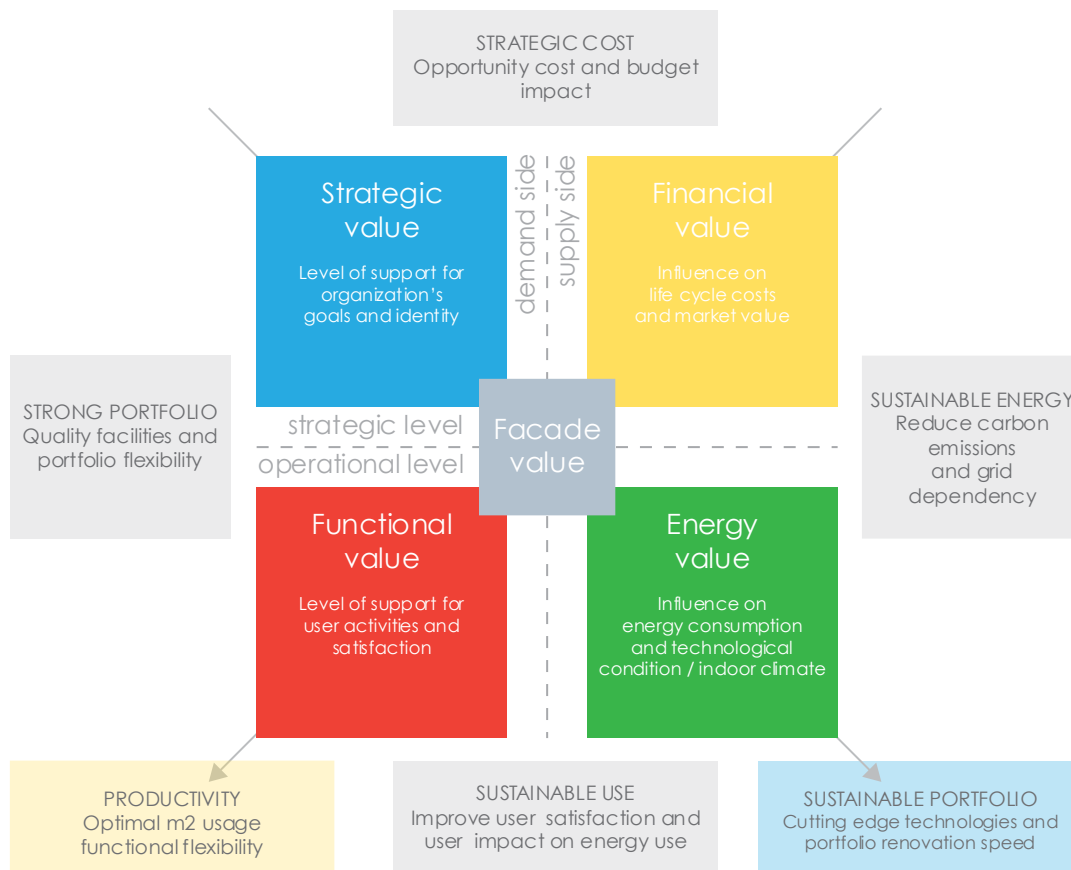


Figure 6 Façade Value adapted form (den Heijer, 2011; Azcarate-Aguerre, 2018)

CLIENT DEMAND (USER)

Demands for a Product-Service System (PSS) from building users, encompassing residential, office, and other types of buildings, can be structured within a universal Functional Hierarchy Model (FHM) inspired by Van Ostaeyen's (2013) approach. This model categorises user demands into three levels: core demands, functional demands, and structural demands.

At the top of this hierarchy are the core demands, which articulate the primary purpose and objectives of the building. For residential settings, these might encompass comfort, security, and privacy, while in office environments, the focus shifts to productivity, collaboration, and accessibility. In specialised buildings like hospitals, educational institutions, or retail spaces, core demands diverge to include health and safety, learning, and customer experience, respectively.

Moving to the middle tier, we find the functional demands, which detail the essential functions that must be delivered to meet the core demands. In a home, this encompasses living spaces, essential utilities, and recreational areas, whereas offices require spaces optimised for work, meetings, and relaxation. For hospitals, functional demands translate into areas for patient care, emergency services, and administrative tasks, while educational buildings prioritise classrooms, laboratories, and libraries.

The foundation of this model lies in the structural demands, representing the physical components and systems that bring functional demands to life. This includes aspects like architectural design, building materials, and essential infrastructures such as heating, cooling, and IT systems. These elements vary significantly across different building types, each tailored to meet the specific requirements of its users.

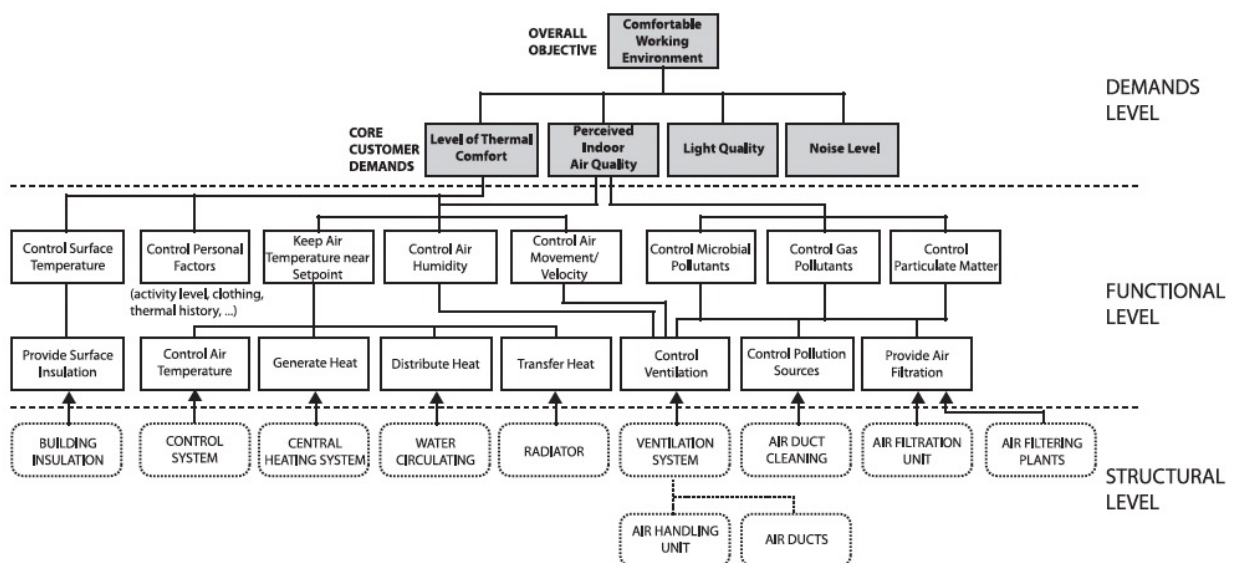


Figure 7 Functional Hierarchy Model (van Ostaeyen, 2013)

REDUCED ENVIRONMENTAL IMPACT:

Façade PSS offer several environmental impact-reducing measures such as prolonged product life, increased resource and energy efficiency, reduced carbon emissions and increased circularity. For example, by decentralising the utility of the buildings, it allows for the distributed functioning of envelope-integrated services according to room occupation trends, thereby avoiding the negative centralised system effect in which large sections of the building are conditioned even when not in use. Additionally, manufacturers can implement design for Dismantlability (DfD), focusing on using dismountable products and standardisation. It aims to extend product lifespan by reducing resource and material use and maintaining their value throughout the product lifecycle. DfD involves proper documentation of materials, designing for easy disassembly, and standardising components. According to Abuzied et al. (2020), successful DfD considers the destination of each component, revenue, labour costs, and disposal costs. Key variables affecting deconstruction cost-effectiveness include type, labour costs, disposal costs, salvage market availability, and market demand for used materials. However, for the case of retained ownership, as is with the façade PSS, aluminium framing could be directly reimplemented in the construction cycle for new façades. Furthermore, building structures are often designed to last 50 to 200 years, and interior finishes and furniture may be updated every 5 to 10 years, the technical service life of building services typically ranges from 15 to 20 years. Building envelopes are expected to last between 20 and 40 years. Integrating these systems on the building's exterior can streamline and synchronise the processes of renovation and system replacement, both in terms of logistics and material usage. (Azcarate-Aguerre, 2017)

COGNITIVE

In the realm of Product-Service Systems (PSS), cognitive settings play a pivotal role for clients, providers, and financiers alike, shaping their understanding and actions within this innovative framework. The cognitive setting for the demand side encompasses their grasp of façade PSS and the relevance of it to their portfolios. However, determining the Total Cost of Ownership (TCO) poses difficulties, as allocating capital costs, maintenance expenses, and energy costs to specific areas and users can be complex within large organisations or in the context of sizable buildings (Azcarate-Aguerre, 2018). By delving into historical service data and projected service costs, clients can enhance their ability to identify PSS implementation opportunities. Potentially accelerating the renovation process of their portfolio. With regards to the façade provider, even though the technological readiness is there, the effective communication of critical information and pricing models is still behind. Without clear demarcations of the exact PSS offering and contractual and duration agreements, it is difficult to convince clients of the long-term value they provide. Standardised contracts can, for example, lower legal costs and increase efficiency. Finally, from the financier's perspective, circular businesses tend to offer greater long-term stability and profitability, yet this aspect is frequently disregarded in the current risk assessment practices of financiers. Consequently, there exists a necessity for the creation of risk models that factor in the significance of circular business (CCA, 2020).

SETTING:

NORMATIVE

SETTING:

The normative settings are the familiarity with and attitude towards façade PSS by the involved stakeholder. For clients, being frontrunners in adopting novel innovations can be seen as a barrier. For this reason, awareness of colleague or competitor organisations might increase the willingness of clients to incorporate PSS in their portfolio as well. This could lead to scalability, which in turn could result in more favourable financing conditions and a diffusion of administration costs (CCA, 2020; Copper 8, 2020). The same goes for manufacturers who are transitioning to the offering of PSS. If they see competitors tapping into new sources of revenue and successfully avoiding the “service paradox” (Gebauer et al., 2005) or the stagnation of profits despite servitisation, they may be more willing to evolve their business models. As mentioned above, the financial industry is currently working to develop new ways to evaluate and finance PSS providers. When this becomes normalised, it will likely trigger a larger embracement of PSS across many industries.

REGULATORY

SETTING:

In the realm of policy and legislation, adopting Product-Service System (PSS) contracting models marks a significant shift from traditional legal practices that have been established over centuries. These innovative and relatively new contracting models introduce additional risks for all parties involved in the PSS project. These risks can lead to disputes over the long-term contracts typical in the built environment or result in increased complexity and financing costs (Azcarate-Aguerre, 2018). The ruling by the Dutch Supreme Court (ECLI: NL: HR: 2018: 424, 2018) established that if the client becomes insolvent or defaults on payments during the contract term, the PSS provider has the right to terminate the service lease and retrieve their PSS from the property. Conversely, if the PSS provider is unable to provide satisfactory

service, the financiers of the PSS have the authority to appoint a new provider capable of meeting the contractual requirements. This authority is known as the “step-in-rights” of the PSS financier (CCA, 2020).

Additionally, there is the issue of “accession”, which is particularly relevant to large building projects that involve Product-Service Systems (PSS) like facades or exterior skins. Accession is a building law principle that refers to the situation where the land owner becomes the owner of any building on that land without the need for a transaction. For example, when a facade is installed on a building, it could legally become a permanent part of the building, making it challenging to separate the ownership of the facade from that of the building.

To address the complexities arising from accession in rental PSS agreements, the Dutch Supreme Court has established a new rental legal framework (ECLI: NL: HR: 2018: 424, 2018). This approach is designed for facades that are modular and detachable, allowing them to be installed and removed without causing damage to the main structure. Under this framework, managed by a Facade Service Company (FSC), the rental of a facade PSS is governed by two main contracts (CCA, 2020):

The FSC rents the points on the building where the facade is attached from the building owner. This is set up through a rental agreement with either the building owner or the property owners association (POA). The contract gives the FSC the right to use these attachment points and later reclaim the facade. The agreement may specify a recurring or one-time fee for this right. Alongside this, a separate service contract outlines the services provided by the FSC to the building owner or the POA. These services include installing, maintaining, and updating the facade. For these services, a separate, periodic fee is charged.

BUSINESS

In Product Service System (PSS) models, revenue generation diverges significantly from conventional sales models. Instead of immediate financial returns, PSS spreads revenue over an extended period, delaying the recovery of initial investments. This characteristic, highlighted by Vermunt et al. in 2019, contrasts with traditional sales models that offer quick financial returns. Despite the potential for higher long-term revenue per product, PSS demands substantial upfront investment and often relies on external financing, as noted by Mont, Dalhammar, and Jacobsson in 2006. Attracting such financing is crucial for growth, as it signals market acceptance and leads to better credit terms. However, securing external financing, especially from traditional institutions, remains challenging for product-service companies, as emphasised by Kirchherr et al. in 2018.

Banks employ various methodologies, known as lending technologies, to extend credit and mitigate risk. These include cash flow-based, asset-based, and relationship-based technologies, which are often combined in practice (Toxopeus, Achterberg & Polzin, 2018).

Investors and lenders follow specific strategies to determine suitable sectors and projects for investment. Their primary goal is to allocate funds to businesses and projects that offer substantial benefits. Each financial institution has unique criteria for issuing credit, guided by regulations that help manage risks. The standard process for assessing creditworthiness typically begins with legal compliance and evaluates the 5 Cs of credit: character, capacity, capital, collateral, and conditions. For quantitative analysis, factors like estimated loss, historical data, and various Key Performance Indicators (KPIs) are used (Colas et al., 2018).

Reducing risk in a product-as-a-service model involves lower vulnerability to physical risks due

VIABILITY:

to less reliance on raw materials and resources, as indicated by Tukker (2004) and the Ellen MacArthur Foundation (2019). This reduces the impact of climate change and resource shortages on costs and revenues, lowering default likelihood (Connell et al., 2018). However, models like Merton's do not account for climate change uncertainties and risks.

Implementing project portfolios can further reduce risk. The interaction among projects within a portfolio can lower the total risk compared to managing projects separately. A well-managed project portfolio diversifies risk across various projects, as highlighted by Teller (2012) and Martinsuo (2013). The integrated risk is a cumulative measure of individual project risks influenced by inter-project interactions. However, managing multiple projects together can introduce additional risks, making the total risk a combination of integrated risk and these additional complexities.

2. CONCEPT 2: VALUE

2.1. DEFINING VALUE

When speaking about product-service systems, the word value is used frequently, but its meaning varies depending on the context. Within this research, the definition of it will therefore also be in multitude.

The most common understanding of “value”. It is described as the financial equivalent of the economic, technical, service, and social advantages that a customer company gains in return for the price it pays for a product, factoring in the offerings and prices from competing suppliers (Anderson & Narus, 1998).

However, den Ouden (2012) suggests that there are four levels of value perceived as dependent on the context, and it is necessary to differentiate between them. These levels are value for users, value for organisations, value for ecosystems, and value for society, as illustrated in Figure 7. Den Ouden indicates that these value levels can be observed from four social science perspectives: economy, psychology, sociology, and ecology.

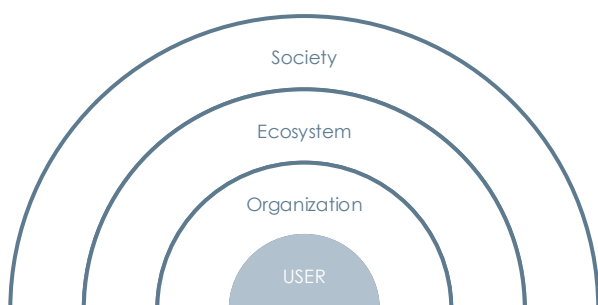


Figure 8 Value framework, value levels adapted from (den Ouden, 2012)

User Value: The expectation is for the user to engage with the system, product, or service. This involves crafting a value proposition that appeals to the user's interests and needs. Neglecting these values can lead to users abandoning the product or service, thereby diminishing the overall potential value of the innovation. (Den Ouden, 2012). In PSS, the concept of value creation and exchange shifts to value co-creation (Vargo and Lusch, 2004). Users now are involved actors in the process of value creation, delivery, and consumption (Edvardsson et al., 2021)

Organisation Value: Values, regarded as qualities of worth, are identified as specific attributes with inherent worth that can be actualised through a product, as outlined by Vos in 2020. Traditionally, this worth was primarily viewed in economic terms from an organisational perspective, as noted by Heskett (2009). However, the concept of value creation in design has evolved beyond just economic aspects. Other types of value are identified, such as functional value, social value, and environmental value (Vos, 2020).

Ecosystem Value: The concept represents a network of varied organisations that are part of broader systems, each fulfilling unique functions within the ecosystems. These ecosystems extend beyond traditional value chains, focusing more on the expertise, skills, and interactions that characterise the specific position of each organisation within this larger network.

Societal Value: This value encompasses both the benefits and often overlooked indirect costs, such as environmental impact and social well-being, influencing the quality of life and requiring a more integrated approach to innovation that accounts for potential negative effects while aiming for societal improvement.

According to den Heijer (2013), there are four types of performance criteria that organisations in corporate and public real estate management are focussing on. In the built environment, the demand and supply sides are connected through these criteria on a strategic and operational level. These criteria are linked with four types of values: organisational, financial, functional and energy value. These values interact and need to be balanced in each decision about the built environment.

When comparing the organisational values in the framework by van Ouden, it becomes clear that these are very similar. Replacing the four social science perspectives in the framework by van Ouden with the four types of values by den Heijer puts the entire value chain in the context of the built environment.

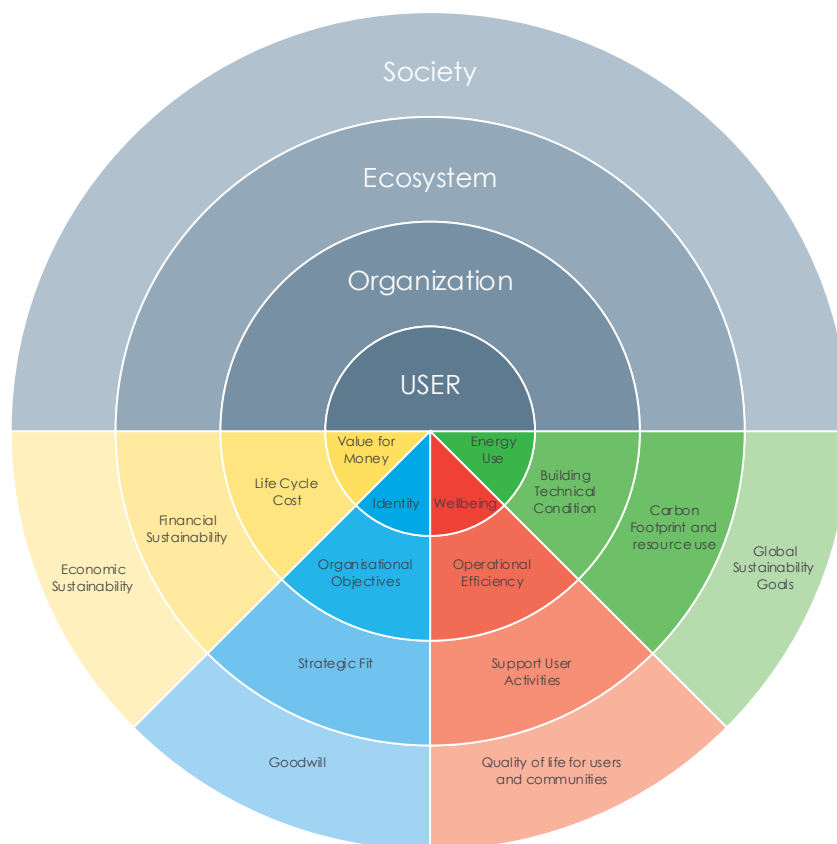


Figure 9 Value framework adapted from (den Ouden, 2012; den Heijer 2012; Azcarate-aguerre, 2018)

2.2. DEFINING COST AND VALUE METHODS

Within this research, three concepts are used extensively to talk about the value captured in a product (-service system) during its useful life: Total Cost of Ownership (TCO), Total Value of Ownership (TVO) and Total Value of Access (TVA). The goal of these tools is to assign monetary measures to costs and values so that they can be taken into consideration when making an investment decision. This will result in a more substantiated and holistic assessment of the options available.

The first method is the TCO, a conceptual management and accounting tool used for assessing and understanding all costs related to the procurement of goods and services from the supplier (Wouters et al., 2004). This deviates from traditional methods, focussing on price exclusively. While the scope of a TCO may vary for different products, the basic premise is the initial investment, plus its ongoing capital, operating, maintenance, and eventually decommissioning expenses (Wynstra, Hurkens, van der Valk, 2004; Azcarate-Aguerre et al., 2016). This method does not, however, capture value yet. This can be seen within the value framework as only considering the User/Use level.

Because the cost components are concrete and easily quantifiable, they become increasingly important for investment decisions. However, it fails to incorporate the added emergent benefits or liabilities. In order to consider these contributions, the concept of Total Value of Ownership has been introduced (Wouters et al., 2004). The TVO incorporates the transcended values of the client level. Here, the expenses determined by the Total Cost of Ownership approach are offset by the anticipated benefits of the contracting method compared to other options. These benefits include energy savings, enhanced user comfort, reduced workload for

facility management staff, increased property value, and reduction of greenhouse gases, among others (Azcarate-Aguerre et al., 2016).

Lastly, there is the Total Value of Access. Azcarate-Aguerre et al. (2016) define this as “the customer/client having access to all the Values the product-service delivers in the TVO without being exposed to many of its traditional liabilities”. While this is, in essence, true, it still considers the client/user the intended beneficiary of innovation, and the flow of value is one-directional from providers to users. It should shift the concept of value creation and exchange to value co-creation (Vargo and Lusch, 2004). The value-creating process is a collaborative endeavour (Prahalad & Ramaswamy, 2004). Clients/users are active participants (co-creators of value) in the process of value creation, delivery, and consumption (Edvardsson et al., 2021; Prahalad & Ramaswamy, 2004). For this reason, the research considers the TVA as the total value created by a product-service offering, incorporating all levels of value.

2.3. CURRENT VALUATION METHODS

In the following section, an overview of the valuation methods of PSS will be presented based on the work by van Ostaeyen (2014). This will be followed by two applicable value/cost modelling methods. These are based on the TCO and the TVO. The TCO calculation will be expressed in the form of a Life Cycle Costing analysis. This is a more widely accepted valuation tool.

LIFE CYCLE COSTING (LCC) AND TCO

Life Cycle Costing and TCO calculations determine the same thing. However, LCC is what is often referred to regarding the method, and TCO is used more in communication. The TCO methodology is currently the most common valuation methodology. LCC is based on deconstructing the project life cycle into a Cost Breakdown Structure (CBS) (van Ostaeyen, 2014). The cost often includes initial investment, plus its ongoing capital, operating, maintenance, and eventually decommissioning expenses. Resulting in the following formula:

On the other hand, the fundamental framework of Life Cycle Costing (LCC) revolves around the Product Life Cycle (PLC), which encompasses all stages in a product's tangible lifespan, starting from its inception to its eventual discard into waste channels. The PLC is divided into four distinct phases: design, production, utilisation, and End-Of-Life. Both the TCO and LCC can be expressed as a Net Present Value (NPV). The 't' represents the time horizon of the analysis. The variable 'i' is the discount rate, which plays a crucial role in balancing the costs occurring presently and those in the future. A commonly used discount rate is the company's Weighted Average Cost of Capital (WACC). WACC is the average rate a company is expected to pay to its capital providers, including both debt and equity holders. An important challenge in an LCC assessment lies in determining how one should cope with all relevant risks and uncertainties in the input parameters that influence the analysis (van Ostaeyen, 2014).

$$NPV = C_0 + \sum_{t=1}^T O_t + \sum_{t=1}^T M_t - SAV$$

C_0 the initial construction costs (at time zero).

$\sum_{t=1}^T O_t$ the sum of discounted operation costs at time t.

$\sum_{t=1}^T M_t$ the sum of discounted maintenance costs at time t.

SAV the discounted salvage value = $RV_T - DC_T$.

RV_T the discounted resale value (at the end of the analysis period).

DC_T the discounted disposal costs (at the end of the analysis period).

T the analysis period in years (project life-cycle).

WHOLE LIFE COSTING (WLC)

The key takeaway from the aforementioned definitions and explanations is that Life-Cycle Costing (LCC) focuses on both current and future expenses, aiming to integrate these costs to support decision-making. It's important to differentiate LCC from Life-Cycle Assessment (LCA), which exclusively examines environmental factors without considering economic aspects (Pelzeter, 2007). According to BS ISO 15686-5:2008, WLC is the "methodology for the systematic economic evaluation of all life-related costs and benefits over a defined analysis period, as specified in the agreed scope." Consequently, WLC is regarded as more comprehensive than LCC, as it not only addresses the economic lifespan but also the entire duration of a property's existence. This includes non-construction costs such as financing, business expenses, revenues from sales or disposals, as well as external social and environmental costs and benefits (Liapis, 2013).

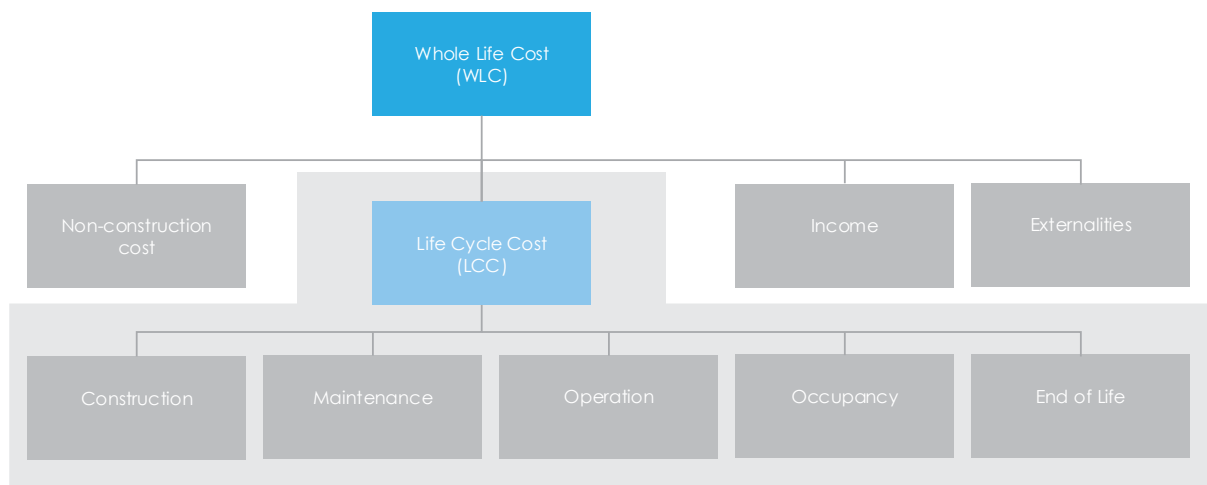


Figure 10 Whole Life Cost framework adapted from (Liapis 2013)

TOTAL VALUE OF OWNERSHIP

Alternative to the LCC and WLC methods, there is the Total Value of Ownership (TVO). In essence, it comes down to the represents the aggregate of a project's complete costs and its overall value. This includes capital expenditures like the initial investment made in the first year, opportunity costs, and the indexed future cash flows for each anticipated year of the project's operation. (Davis, Coony, Gould, & Daly, 2005; van Ostaeyen, 2014), but it also incorporates a range of tangible and intangible factors as specified by the decision-maker. In scenarios where an investor is comparing alternative projects that deliver similar utility performance, the one with the greatest TVO is considered the most (financially) advantageous (Azcarate-Aguerre, 2022). A basic approach to the most tangible TVO factors is thus determined by the formula:

$$TVO = -P_x - O_x - M_x - E_x + T_v + R_v$$

P_x is the capital cost of the project's initial investment in €/m2 NFA plus the region's bank loan servicing cost.

O_x is the opportunity cost of capital for the project's initial investment in €/m2 NFA at the region's Weighted Average Cost of Capital (WACC)

M_x are the indexed future maintenance costs SUM of $M_1, M_2, M_3, \dots M_x$ in €/m2 NFA, plus the cost of deferred maintenance in a no-renovation scenario.

E_x are the indexed future energy costs SUM of $E_1, E_2, E_3, \dots E_x$ in €/m2 NFA R_v is the indexed value of rental revenue SUM of $R_1, R_2, R_3, \dots R_x$ in €/m2 NFA

T_v is the indexed transactional value of property appreciation SUM of $T_1, T_2, T_3, \dots T_x$ in €/m2 NFA

The extended approach, including softer or less tangible indicators of value, is the TVO + analysis, determined by the formula:

$$TVO^+ = TVO - S_x - H_x + C_v$$

S_x are the indexed shadow carbon costs SUM of $S_1, S_2, S_3, \dots S_x$ in €/m2 NFA

H_x are the indexed costs of a decrease in staff productivity due to poor indoor comfort, SUM of $H_1, H_2, H_3, \dots H_x$ in €/m2 NFA

C_v is the indexed material or components value recovered through, respectively, recycling or re-manufacturing activities, in % of original component value indexed at the end of service life.

03 CONCEPTUAL FRAMEWORK

The valuation methodologies and their relations can be visualised in a framework, as shown below. When overlapping the framework by den Heijer (2011) with the valuation methodologies, it illustrates that the traditional TCO calculation consists mainly of financial metrics while the strategic environmental and user values can be assigned to the externalities in the TVO calculation, as shown in figure X1. From the literature review, it is expected that implementing a facade PSS concept shifts, depending on the payment structures, the TCO part of the Whole life cost to the supplier (fig. 10).

While leaving access to benefits in the form of the externalities with the client. Additionally, it is expected that the initial investment is higher in comparison to a traditional facade to accommodate circular components and higher-quality materials. However, standardised systems can, in turn, be beneficial for the investment cost, legal requirements, downtime and repair and maintenance. However, the planned maintenance is expected to increase, as the supplier bears responsibility for the product now. Furthermore, shifting to a service contract model potentially allows for increased flexibility, and so, too, does a standardised modular system.

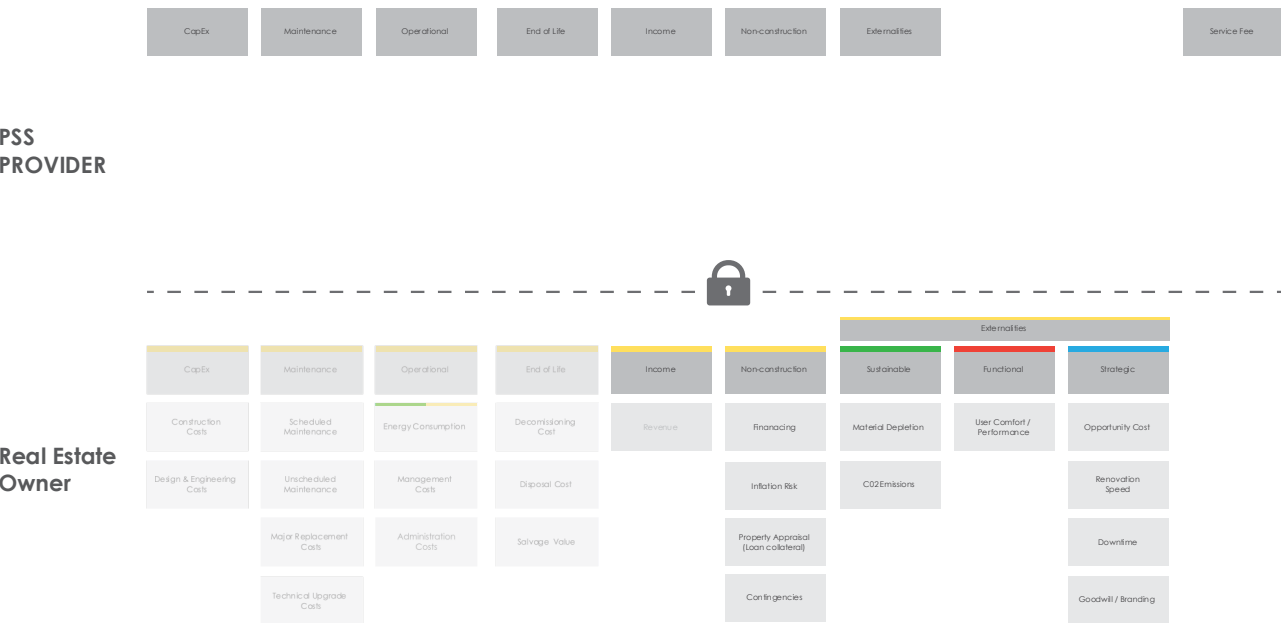


Figure 11 Total Value of Ownership (Own figure)

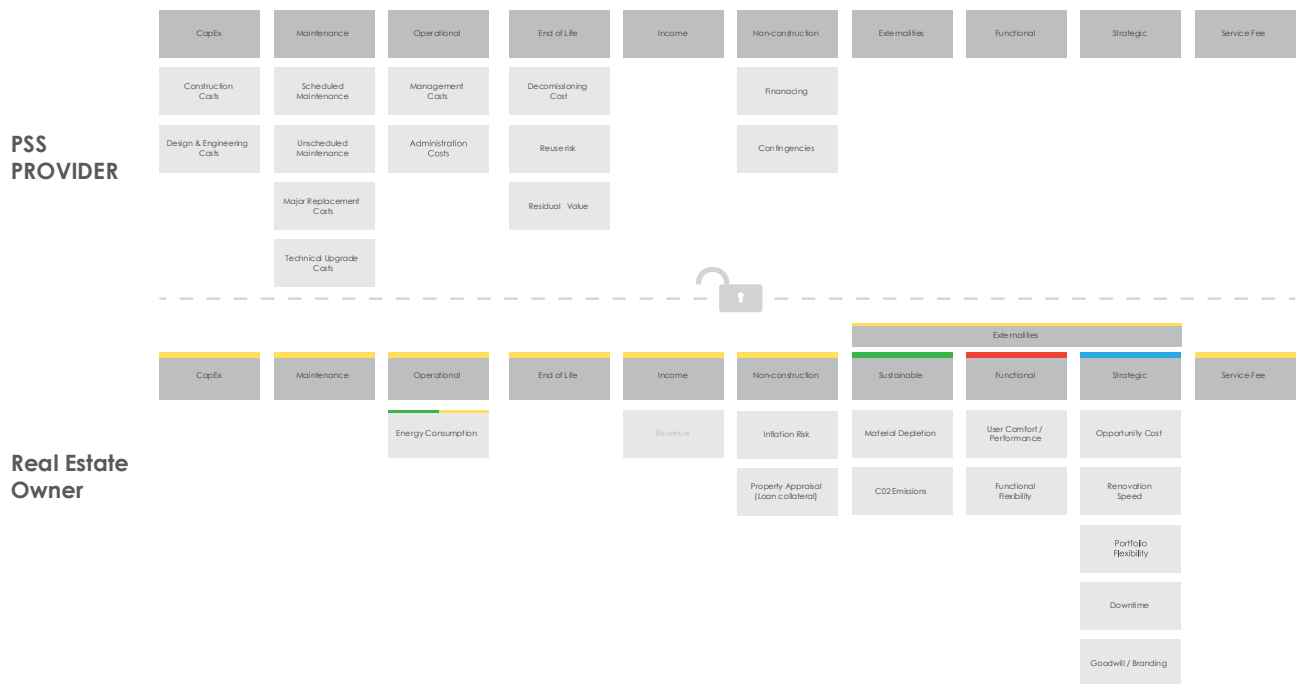


Figure 12 Total Value of Use (Own figure)

04 EMPIRICAL RESEARCH

1. INTRODUCTION

This chapter explores the empirical research done in relation to the ongoing project, now at stage “Leasegevel 2.0”. It will consist of the following parts:

1 – an analysis of the first two completed stages of the “lease gevel” project: the “EWI-pilot project” and the “leasegevel 1.0”; 2 – an analysis of the third un-completed stage: “leasegevel 2.0”; and 3 – the financial simulation. The aim of this chapter is to answer the sub-questions 3 – 5:

SQ3: What are the drivers for ((semi-) public) real estate owners to use façade PSS?

SQ4: What challenges do ((semi-) public) real estate owners face when using a façade PSS?

SQ5: How does the use of façade PSS compare to traditional façade renovation procurement?

The case study research of the first two stages of the leasegevel project consists of an in-depth analysis of the dissertation by Azcarate-Aguerre, published in 2023. The focus will be on chapter 3: “On the use of full-scale pilot projects in this research” for the EWI case and chapters 4 – 8 for the “leasegevel 1.0”. The understanding of the found drivers and barriers will be further corroborated by available documents from during these projects, as well as extensive action research communication with parties involved during that time.

The findings serve as a starting point for the qualitative research done on the leasegevel 2.0 project. By interviewing various parties involved

with the façade as a service project, new insights into the current standing of the implementation of the façade as a service concept are created. Upon completion of this, the findings are compared to the drivers and barriers present at the outset of the first two phases. Highlighting the progress made, barriers that have not yet been resolved and underscoring potential benefits.

Finally, the financial simulation will employ an extensive financial model consisting of a TVO/ TVU calculation. For this, a business case analysis is done from the supplier’s perspective to provide a realistic service fee offering. By comparing the facade PSS case with two alternatives, a better understanding of the value proposition is created. The first is the purchase of the same façade offered in the PSS with an additional full-service contract. The second is a traditional procurement of a comparable non-circular façade with a traditional maintenance strategy.

2. ANALYSIS OF COMPLETED STAGES

The analysis of the two completed stages consists of the case context and details, a description of the product service offering and an analysis of the drivers and barriers encountered.



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2.1. STAGE 1: THE EWI PILOT PROJECT

CONTEXT

The Faculty of Electrical Engineering, Mathematics & Computer Science (EWI, as per its Dutch acronym) at TU Delft is housed in a 68,000m² building, an iconic 1960s structure situated on the university's campus. At the time of its construction, the building was groundbreaking, being the first in the Netherlands to feature a double-skin façade. However, by 2015, due to several technical deficiencies, including building service failures, inadequate user comfort, and fire safety issues, discussions were underway regarding the building's future. In this context, a research team approached TU Delft's Campus Real Estate to propose a pilot project to test the "Façade-as-a-Service" (FaaS) concept. The EWI FaaS pilot project was designed to evaluate the technological maturity of façade and façade-integrated solutions in meeting the comprehensive technical performance demands of a modernised building (Azcárate-Aguerre, 2019). Due to its modular and unitised design, the building served as an excellent experimental site. It also typifies a significant collection of university structures erected in the 1960s and 1970s. These buildings represent a vast potential market for renovation, encompassing millions of square meters in the Netherlands and tens of millions throughout Europe (Azcárate-Aguerre, 2019, den Heijer, 2011).

Project details

Year: 2015

Project size: 4 modular façade panels

Ownership of product: TU Delft

business model: Traditional

Contract: DBFMO (variant)

PRODUCT / SERVICE

A supplier consortium, guided by both the academic team and VMRG's project development team, undertook the engineering of four state-of-the-art panels. These panels were designed to replace a section of the original façade and evaluate their impact on the building's overall performance. The panels were constructed with interchangeable modular components to address a variety of functional requirements and investment levels. The design of these panels followed an ascending sequence in both the complexity of services offered and the intended contract duration. It began with the straightforward "Low-cost Panel," which aimed to extend the building's service life by an additional ten to fifteen years before a more comprehensive renovation would be necessary. Next was the "Supply Services and Energy Generation Panel ", intended to support or even replace centralised building services. The sequence culminated with the "High-end Panels 3 and 4," which showcased advanced systems and technologies such as self-supporting vegetation panels, LED media screens, and high wind-velocity solar shading, among other innovations. By replacing a portion of the original façade with these panels, the consortium could test and demonstrate how such technologies could enhance the building's performance across various metrics (Azcárate-Aguerre, 2016).

DRIVERS

TECHNOLOGICAL READINESS

The pilot demonstrated that the technical components of decentralised, integrated facades are ready for deployment. Systems like Building-integrated Photovoltaics (BiPV), automated sun-shading, and decentralised ventilation can replace centralised systems, presenting an opportunity to enhance building performance and energy efficiency. (Azcárate-Aguerre, 2016).

MODULARITY AND FLEXIBILITY

The modular nature of the facade allows for easy upgrades and replacements, reducing long-term maintenance costs. This ensures that the building's facade can evolve with new technologies without requiring significant reconstruction, positively influencing life cycle cost elements related to building renovation and adaptability. (Azcárate-Aguerre, 2016).

ENERGY EFFICIENCY AND USER COMFORT

Integrated systems like operable windows and smart shading enhance energy efficiency by improving natural ventilation and reducing energy demand for heating and cooling. This can result in a more comfortable environment for users. (Azcárate-Aguerre, 2016).

BARRIERS

COMPLEX SUPPLY CHAIN AND MULTI-STAKEHOLDER COORDINATION

A major barrier was the complexity of coordinating multiple suppliers and stakeholders, each providing specialised components (e.g., BiPV panels, automated systems, and sun-shading). The integration of these systems posed challenges during both the planning and construction phases. (Azcárate-Aguerre, 2016).

FINANCIAL AND LEGAL BARRIERS

The adoption of the FaaS model faces hurdles in aligning with existing financial and legal systems. The current real estate market is accustomed to traditional purchase models, and shifting to a leasing-based service model requires new contractual and financing structures. (Azcárate-Aguerre, 2016).

HIGH INITIAL CAPITAL INVESTMENT

Advanced technologies integrated into the facade require more upfront capital. This forms a significant hurdle for deep energy renovations, as it demands greater initial financial commitment. (Azcárate-Aguerre, 2016).

CONCLUSION

The EWI FaaS Technology pilot (2015-2017) showcased both the potential and challenges of integrating facade-based technologies into building infrastructure. The project demonstrated high technological readiness, proving that decentralised systems can enhance energy performance and user comfort. However, industry gaps in interdisciplinary collaboration and supply-chain management emerged, particularly in coordinating electrical and plumbing connections.

A key finding was the feasibility of applying integrated facade technologies to older buildings like EWI, even if not originally designed for them. While these facades have higher upfront costs, they can be competitive when replacing central building services like heating, cooling, and energy generation via BiPV.

Despite the technical success, achieving a full Façade-as-a-Service (FaaS) model requires addressing broader systemic challenges in financing, procurement, and long-term management—issues beyond the pilot's scope but critical for future implementation.



Image: Broekbakema 2024

<https://www.broekbakema.nl/projecten/civiele-techniek-tu-delft/>

2.2. STAGE 2: LEASEGEVEL 1.0 CITG EAST FAÇADE

CONTEXT

In late 2018, before the East façade of the CiTG building received minor maintenance treatment, the FaaS research team proposed an alternative evaluation to TU Delft's Campus Real Estate Group. This proposal aimed to assess the feasibility of applying the FaaS model to approximately 2,600m² of the CiTG's East façade. Unlike the EWI pilot project, this evaluation went beyond testing technological readiness and focused on addressing key challenges such as long-term project financing, the legal framework, and managerial processes required for the successful implementation of FaaS.

PROJECT DETAILS

PROJECT SIZE: 2600M2

OWNERSHIP: TU DELFT

*BUSINESS MODEL: AS A SERVICE
(ATTEMPTED)*

CONTRACT: 5 YEARS

PRODUCT

The CiTG pilot project involved replacing the old steel façade panels with a new insulated aluminium system. HR++ double glazing was installed, featuring manually operable windows at user height and automatically operated windows near the ceiling, designed to facilitate night cooling during summer. An external automated sun-shading system was also installed, centrally controlled to optimise indoor comfort. However, all automated systems could be manually overridden by users to ensure flexibility in control (Azcarate-Aguerre, 2019).

SERVICE

A full FaaS implementation was not successfully achieved due to several real-life constraints. Additionally, time pressure related to the technical delivery of the project led to fiscal uncertainty, and the market was not yet prepared for large-scale adoption of the FaaS model. This resulted in the TU Delft retaining responsibility for maintenance and management of the façade. Consequently, the traditional maintenance strategy of the TU Delft was implemented. Therefore, the role of the supplier was limited to monitoring the data reported by the digital twin technology on occupant comfort and technical condition of components, which was summarised in an advice report.

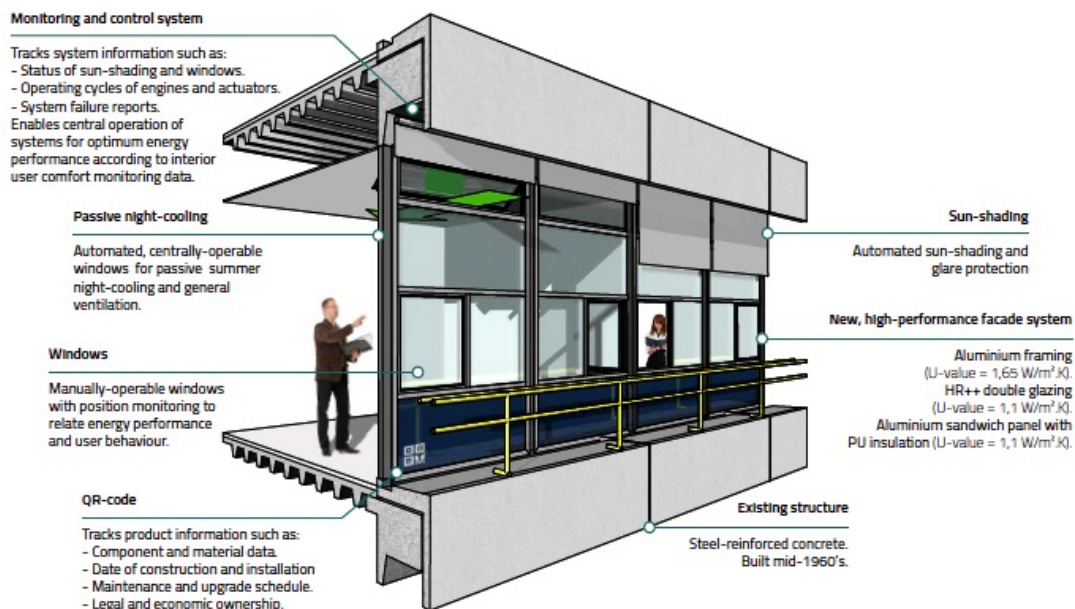


Figure 13 Rendering of new CiTG Facade Leasing renovation solution (Azcarate-Aguerre 2016b)

DRIVERS AND BARRIERS

Azcárate-Aguerre (2023) finalises his dissertation with a conclusion of the drivers and barriers to the implementation of a FaaS system. He considered the technical, financial and managerial dimensions. Below is a summary of the most important benefits and challenges faced during the project.

DRIVERS

ALIGNMENT OF LONG-TERM INTERESTS

FaaS emphasises aligning the long-term goals of building component suppliers (e.g., manufacturers, service providers) with those of clients (e.g., building owners, users). This collaboration ensures that suppliers have a vested interest in the performance, durability, and efficiency of building systems throughout their lifecycle. By retaining ownership or responsibility, suppliers are incentivised to deliver high-quality products and ongoing services, leading to shared benefits, reduced operational burdens, and increased sustainability (Azcárate-Aguerre, 2018).

FINANCIAL ADVANTAGES OF PSS MODELS

Product-Service Systems (PSS) reduce the need for substantial upfront capital expenditure, making sustainable solutions more accessible. PSS models often use pay-per-use, leasing, or service contracts, spreading costs over the asset's life. This reduces the immediate financial burden on clients and allows capital allocation to other business activities, enhancing financial stability and predictability (Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2022).

IMPROVED FUNCTIONAL FLEXIBILITY

FaaS supports designing buildings with functional flexibility to adapt to evolving needs and market trends. PSS models facilitate modular components that can be easily upgraded or reconfigured, reducing renovation costs and downtime. This adaptability extends the useful life of buildings, enhances value, and supports efficient response to changing demands (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2023).

ACCELERATED PORTFOLIO RETROFITTING

FaaS enables rapid energy performance improvements across property portfolios through collaborative retrofitting processes. By leveraging PSS models, building owners can efficiently upgrade multiple properties, achieving regulatory compliance and reducing carbon emissions. This approach accelerates energy savings and increases asset value (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2023).

ACKNOWLEDGEMENT OF RISING MATERIAL RESOURCE VALUE

The increasing economic value of scarce materials encourages stakeholders to focus on material recovery and recycling. FaaS supports circular economy (CE) principles by designing for disassembly and promoting material reuse, reducing disposal costs and generating revenue from recycled resources (Azcárate-Aguerre, 2018).

BANKS AND FINANCIERS TAKING A LEADING ROLE

Financial institutions play a critical role in facilitating the transition to PSS and CE models by developing tailored financial products and standardised evaluation criteria. Their proactive involvement reduces perceived risks, making funding for sustainable projects more accessible and aligning with ethical banking practices (Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2023).

TECHNOLOGICAL INNOVATION AS AN ENABLER

Technological advancements such as smart building systems, Internet of Things (IoT) devices, and predictive maintenance tools enhance building performance and energy efficiency. By leveraging these technologies, FaaS providers can optimise building operations, reduce costs, and increase occupant comfort. Technological innovation also supports performance-based contracts, driving sustainability and cost-effectiveness over the building's lifecycle (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2023).

BARRIERS

MISALIGNMENT OF LIABILITIES IN FINANCING

In PSS models, the ownership and responsibilities between service providers and building owners can be misaligned, creating financing complexities. This divided ownership increases perceived risk due to the lack of traditional collateral, leading to higher borrowing costs and reluctance from financiers. Legal complications and administrative burdens can further hinder the adoption of sustainable projects (Azcárate-Aguerre, 2018).

FOCUS ON INITIAL INVESTMENT COSTS

A common industry practice is to prioritise low initial capital costs, often at the expense of long-term performance. Cheaper, less efficient materials may be chosen to minimise upfront costs, ignoring higher future maintenance and operational expenses. This short-term focus leads to increased energy use, frequent repairs, and lower durability, ultimately reducing the building's overall value. The emphasis on minimising initial costs undermines the adoption of Product Service Systems (PSS) and circular economy (CE) models, which rely on long-term value generation (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2023).

LACK OF VALUATION STANDARDS FOR EXTERNALITIES

Conventional valuation methods often fail to account for externalities like environmental impact, user comfort, and energy efficiency. This omission results in sustainable projects appearing less financially viable, making it harder to secure funding. As a result, these projects are perceived as riskier investments, leading to unfavourable financing terms that deter the adoption of PSS and CE models (Azcárate-Aguerre, 2022).

SHORT-TERM INVESTMENT CYCLES

Investors often focus on short-term returns (5-10 years), neglecting long-term benefits. This short-sighted approach discourages investments in durable, energy-efficient materials that may have higher initial costs but offer savings over a building's entire lifecycle. The lack of long-term planning results in higher operational expenses and reduced building value, contributing to premature obsolescence and increased lifecycle costs (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2023).

LEGAL AND REGULATORY BARRIERS

Current regulations are not designed to support innovative PSS contracts or circular practices, often imposing constraints on ownership structures and material recovery efforts. Legal restrictions and compliance issues increase costs and complicate project implementation. Navigating these legal challenges can discourage stakeholders from pursuing sustainable models despite potential long-term benefits (Azcárate-Aguerre, 2017; Azcárate-Aguerre, 2018; Azcárate-Aguerre, 2023).

CONCLUSION

The evaluation of the Facades-as-a-Service (FaaS) model for the East facade of TU Delft's CiTG building provided valuable lessons on the practicalities of transitioning from traditional facade management to a service-oriented approach. While the project initially aimed for a full FaaS implementation, real-world constraints such as time pressure, fiscal uncertainty, and market unpreparedness resulted in the continuation of TU Delft's traditional maintenance practices. As a result, the supplier's role was limited to monitoring performance through digital twin technology and providing advisory feedback rather than assuming full operational responsibility.

The study identified several key drivers for the FaaS model, including the alignment of long-term goals between stakeholders, financial predictability through reduced upfront costs, and the ability to rapidly retrofit building portfolios. The integration of technological innovations further supports enhanced performance and sustainability outcomes, showcasing the potential advantages of a service-based facade approach.

However, significant barriers emerged, such as the industry's focus on minimising initial investment costs and the lack of standardised methods for valuing externalities like environmental impact and user comfort. Misalignment of ownership and liabilities between building owners and service providers also complicates financing and legal structures, making it difficult for stakeholders to fully commit to a FaaS model.

In summary, while FaaS offers promising benefits in sustainability, financial stability, and functional flexibility, overcoming these challenges is crucial for broader adoption. Addressing financing complexities, improving valuation standards, and developing clear contractual frameworks will be essential to unlock the full potential of facade PSS. This case study provides a foundational understanding of the hurdles and opportunities in implementing facade-as-a-service, guiding future efforts in advancing service-oriented building solutions.



Image: Steven Lek 2018

https://nl.m.wikipedia.org/wiki/Bestand:Civil_Engineering_and_Geosciences_building_23_Delft.jpg

3. ANALYSIS OF STAGE 3

Unlike the leasegevel 1.0 project, the West Façade project did not come off the ground, and the research proposal was halted prematurely. In the following part, the leasegevel 2.0 project will be evaluated through a series of interviews. This part of the research relies on the submitted research proposal, standardised contracts and legal documents produced in anticipation of the project, working sessions and various other files and documents created since the completion of the first iteration of the CiTG case.

3.1. STAGE 3: LEASEGEVEL 2.0 CITG WEST FAÇADE

CONTEXT

Reflecting on the FaaS 1.0 project, the initial plan to renovate the West façade of TU Delft's CiTG building appeared promising due to several favourable factors. The East façade had been renovated in 2019, providing extensive data on architecture, façade engineering, energy performance, and user comfort. This prior renovation reduced development costs and allowed for direct comparisons between the updated East side and the outdated West side, which still featured a 1960s uninsulated profile system with single glazing.

The West façade had long been a source of discomfort for occupants. Malfunctioning sun-shading devices and windows led to excessive heat and glare during summers, while significant heat loss in winters resulted in high energy consumption. Complaints from the Faculty of Civil Engineering and Geosciences highlighted the urgency for improvement. The plan was to implement the new Ciskin façade technology, maintaining the building's original aesthetic to avoid bureaucratic hurdles like environmental permits and aesthetic committee approvals.

However, despite the groundwork laid, the project was not realised due to various unresolved barriers. The West façade presented a complex and politically sensitive case. Its monumental value required careful preservation, complicating renovation efforts. The presence of hazardous materials like asbestos and Chromium6 posed significant health and safety challenges. The enormous scale of the façade further amplified these issues, making the CiTG building a difficult candidate for the FaaS 2.0 initiative.

Previous attempts to implement the Facades-as-a-Service model had already encountered hurdles. In late 2018, an evaluation aimed at applying the FaaS model to the East façade went beyond testing technological readiness, addressing long-term financing, legal frameworks, and managerial processes. Nevertheless, full implementation was hindered by real-world constraints such as accounting complexities, banking sector hesitance due to risk aversion and uncertainties, and a market not yet ready for scaling up.

Although economic conditions eventually evolved and new solutions emerged—including the innovative Ciskin façade system and stronger policy support—the cumulative challenges specific to the CiTG building proved insurmountable at the time. The project team recognised that focusing on other potential projects with fewer obstacles would be more feasible. In retrospect, while the FaaS 2.0 project on the CiTG building's West façade did not come to fruition, it provided valuable insights into the complexities of retrofitting historic and large-scale structures.

PROJECT DETAILS

PROJECT SIZE: 2600M²

OWNERSHIP: TU DELFT

*BUSINESS MODEL: AS A SERVICE
(ATTEMPTED)*

CONTRACT: 30-60 YEARS

PRODUCT:

The Ciskin circular facade is a fully customisable, detachable, and reusable architectural system made entirely from harvested raw materials (Fig. 13). It incorporates biobased parapet modules equipped with installation hatches to facilitate practical maintenance. This facade features automation capabilities that control electric bottom-hung windows for night ventilation. It also manages sun blinds by interfacing with the existing weather station, allowing adjustments based on real-time weather conditions. The sensors responsible for opening and closing, as well as the switches for the sun blinds, operate on kinetic energy, eliminating the need for batteries or wired connections.

External sun protection screens are integrated into the facade and are automatically operable via a smart algorithm that responds to environmental factors. This system adjusts shading and light penetration to contribute to energy efficiency and occupant comfort. Additionally, the Ciskin facade includes a monitoring feature integrated into a facade dashboard visualization, which is also operational for the East facade. Facility Management uses this dashboard for ongoing maintenance and service, accessing real-time data to monitor the facade's performance.



Figure 14 Ciskin façade concept from (Alkondor, 2023)

SERVICE:

The "Façade as a Service" (FaaS) model, to be offered by Alkondor Hengelo in collaboration with TU Delft, will provide a circular and sustainable solution for the management, maintenance, and operation of building façades. Under this agreement, should it be finalised, the service provider will retain ownership of the façade, while the client will be entitled to its full use, aligning with sustainability goals that promote the reuse and recycling of materials. The service provider will have the right to remove and repurpose the façade at the end of the service contract, reinforcing the principles of a circular economy.

The FaaS model will encompass full-service maintenance, including both preventive and corrective actions, ensuring that the façade remains operational and aesthetically maintained for the duration of the contract. Maintenance will cover technical elements such as windows, sun blinds, and automation systems. Clients will be able to choose from multiple service tiers, including Gold, Silver, and Bronze, each offering different levels of service. Should the Gold tier be selected, comprehensive maintenance will be provided, while lower tiers will allow for more limited services or maintenance on a per-event basis.

Aesthetic and functional upkeep will be a key part of the service, with regular cleaning of glass and aluminium, as well as preventive care for technical components to prevent operational downtime. Continuous monitoring will ensure that key functions like window and sunblind operations perform reliably, which will be particularly important in environments such as TU Delft. Payment for the service will be arranged as an annual fee, covering the agreed maintenance activities.

Should additional services be required outside the scope of the contract, these will incur extra fees. Pricing will be indexed annually to account for inflation, ensuring fair and transparent cost adjustments over the term.

Based on the experience of the 2019 East CiTG façade project, a fall-back buy-out scenario was to be developed as part of the contract. This would involve a pre-determined price chart with depreciating values per year, allowing the building owner to purchase the façade at its outstanding value should they wish to revert to traditional ownership. This would enable the building owner to recover full ownership of the façade by paying a fixed price, based on the year of purchase, should the need arise. This scenario would provide additional flexibility for the building owner, ensuring that a structured path to ownership transfer exists.

DRIVERS AND BARRIERS

In the following part the findings from the case study interviews will be discussed. The complex nature and extensive actor network of the project resulted in opposing connotations regarding various matters, as well as inter connected drivers and barriers. The various themes will therefore be discussed holistically.

LEGAL, CONTRACTS AND RISK

One of the two most recurring themes during the interviews was the contractual agreements to be made. It is the foundation for every aspect of the case and is the biggest determinant for risk, the other common denominator. Risk analyses determine the probability of default which in turn determines the loan-conditions available to PSS-provider. High risks result in high interest rates producing an unfavourable business proposition offered to the client. Additionally, the contract is detrimental for real estate appraisers in the valuation of properties. From the perspective of (semi-) public real estate owners however, another barrier has been mentioned; the requirement to comply with policy documents. The overarching theme of contract and risk will be elaborated further in the various themes.

Beyond the influence the contract has on the project there are several legal implications involved with transitioning to a full product-service model. The biggest problem mentioned is the law of accession. As discussed in the literature section, a work around has been created through the renting of attachment points. When asked, a legal expert said that this no problem any-more and that there is a legal precedent. With the introduction of the CiSe (Circular Service) platform, providing standardised contracts within the field of as a service product, several common problems are overcome. These standardised contracts also reduce legal cost, making as a service more

accessible. Furthermore, problems with the law of accession would come into play in the scenario of bankruptcy of the building owner, in this case TU Delft. It is therefore extremely unlikely. As the ‘too big to fail’ nature of the University, and (semi-) public real estate owners in general, is crucial for financiers to even consider such a project.

FINANCEABILITY

With the imminent changes regarding sustainability and circularity policy ahead, new innovative solutions are certain to be created. To enable these, new ways of assessing risk and business models are required. This sentiment is shared by the Dutch banking sector. Although still modest in their implementation, a statement of intent has been made. However, a full commitment has not yet been made and with current interest rates are already at 6-7%, there is a risk they could rise to 8-9%.

“We could say, as banks, are committed to this (CiTG project) against 5 or 6% interest rate. Build on a track record and gather data. Then the next time, you will do it with the municipality of the Hague or NS and so you will build a portfolio. Then eventually you can look to involve public banks who can offer better interest rates.”
– Financier 1

While commercial banks would be detrimental in the start-up face of financing façade PSS, truly implementing these concepts on a national level requires scalability. Commercial lending rates are not competitive enough and so there is a need for a different kind of financier. One such option is the “Waterschapsbank”. An institution focussed on public sector and sustainability, a lot of experience in Project Finance and long-term lending. The waterschapsbank does have several requirements but can potentially offer more affordable rates. *“In general, you see that we ask far lower interest rates than commercial*

bank. This is because of our funding structures". Although, they too can not provide any concrete numbers yet. One of such requirements is scale. They will not get involved if the investment fund is below a threshold of roughly €20mil.

"We would really like to see projects like these be developed further, and do see the potential for housing corporations, for example. What the problem with this case is, is that it is on the small side for us. We do not have the capacity to undertake these kinds of specialty projects. It would help us a lot if the university were to scale up the portfolio size to around 10 projects. Then it would become interesting for us. Furthermore, from the public sector perspective we feel that we do not need to take on the role of commercial banks." – Financier 2

Furthermore, there are strict conditions regarding their loan recipients. A strong relation to public value is therefore a must. While limiting the scope of potential future projects, it is still in line with the visions of both the provider and commercial financiers.

"Because we are a public sector bank, the relation to the public is crucial for us to be able to give out the loan. In a PPS construction the role of the public sector needs to become very apparent. For housing corporations, it could be very interesting as they have limited cashflows and capital available for renovations or new construction. It would be easier to have a positive cashflow from their business compared to a university" – Financier 2

Shifting from traditional asset-backed loans to cash-flow based chain financing requires strong partners within the chain. The need for stable parties and strong contractual agreements is therefore substantial. It is noted that without the AAA/Aaa-rating of the TU Delft there would be no project. Conversely, the long track record of façade manufacturer backed by one of the

largest global aluminium producers is almost equally important.

"As a bank you always look at can they pay. In this case you have a very good debitter, the TU Delft. If it were a MKB company that would want to do it, we would not even consider it"

– Financier 1

FINANCIAL VS OPERATIONAL LEASE

Under laws and regulations and the treasury statute, the TU Delft is limited in what they are allowed to do when it comes to investing and borrowing. Depending on whether the construction qualifies as financial lease (a loan) or operational lease, they have to deal with the rules and conditions set by the counterparty they do business with. Based on Financial Control's review of the draft agreements, the construction appears to qualify as a financial lease, and therefore in breach of the rules. A review of the final documents, possibly supplemented by a review by the external auditor, would still need to take place for a final opinion.

"One of the cases from the treasury statute is with whom the university will enter into loan agreements. One of the statutes states that we only do business with big and stable financial institutions with a certain rating. We don't want many smaller financiers and uncertainty. The problem is that the characteristic identifies it as a financial lease and that is in essence a loan. Then we would have a loan with a small private party and not in line with our code of conduct."

– Real Estate Owner 1

Contrary to this the it is in the opinion of a legal expert, with a lot of experience in as a service contract, that this is not the case.

“I think a facade has a service in which the full risk lies with the supplier to which there are no purchase options to zero. You know, that's also kind of what happens with financial leases, isn't it? If at the end of the lease term, then I formally take over. Yes, then it's very much a buy on instalment with its own caveats and that's a Financial lease. But that's just not the case, so you can say it is , But that's just not the case. Nor have they suddenly entered into a financial lease for a cleaning company which is there with cleaning machines doing the cleaning of the buildings at TU Delft itself.”

– Legal Expert 1

The ING bank defines the two options as follows: “Operational Lease is a form of ‘renting’; financial lease is a form of ‘rent-to- purchase’”. Operational lease is attractive if you do not want to run any economic risks such as wear and tear or rapid depreciation. With Operational Lease you do not own the asset as with financial lease and you avoid the economic risks of financial leasing. With full operational leasing, risks such as depreciation or user damage are borne by the lease and/or insurance party. However, you are not entitled to tax benefits such as investment deductions or fiscal depreciation, nor to subsidies. Lastly, operational leasing is often more expensive than financial leasing, as the leasing company as owner bears the economic risks. This depends on the term.” (ING, 2024).

PROPERTY VALUE AND TAXATION

The TU Delft intends to use their buildings as collateral for loans in the future. It is in their opinion that a demountable facade that is not owned by TU Delft would have a negative impact on the value of the collateral and thus on the borrowing capacity. There has been coordination with the Rijksvastgoedbedrijf, the appraiser responsible for determining the value of the collateral, and the conclusion was that it is correct that the concept by itself has a negative impact on the collateral.

“When you start adding elements to a building that can be demounted or are not in ownership, then that can cause conflict. They look specifically at how does it work, if we were to get the building asset. Do we need to take on the concept or do we need to negotiate. That results in the end in a negative effect of what they are willing to lend us” – Real Estate Owner 1

However, because of the size of this one project compared to the entire campus, this is negligible. In other words, for one project this concept does not pose a problem for TU Delft, but for a broad roll-out of this concept to several buildings on the campus it does. With this in mind they also do not feel that this case would result in a realistic case suited for scalability. However, this building appraisal is not set in stone and has a high level of subjectivity. In conversation with an external appraiser, it became clear that for the appraisal of a public real estate building like a university building the most common method used is the building costs method. The majority share of the value is gained from the location and residual part is based on the construction cost.

“There are the three rules of real estate: location, location, location. I find it a bit of a mundane statement, but it is true. Then of course the square meters are also very important” – Building Appraiser 1

As long as the contractual agreements are constructed in such a way that there is no risk of a façade-less building, there is no reason for the building appraisal to be lower than with a traditional façade.

“What does it do with the value of the building? Nobody can tell you because nobody knows. It is my job to assess the risk, that is what banks want to know. The university is not the risk, the supplier is. So, what happens if they go under? If you can make contractual agreements ensuring the building will not be without a façade, then there is little risk. If I’m convinced it will be sorted out through the contract then I will assess it as normal. Then I only see benefits for the user as they don’t have to invest the capital at the front end” – Building Appraiser 1

Although it is suggested that with the high-level maintenance the façade will provide the building with a higher value over the duration of the contract, a future appraisal can’t be made in the present.

“As an appraiser, you are not allowed to give the future value. You may, however, make an estimate. What I have seen in the last 30 years is that rules change and things change and that can be about insulation standards. It could also be for light penetration. But buildings age, locations age and then 30 years is a long way off, to say the least. To say it becomes worth more. I don’t know. I think that it doesn’t have to be worth less If it is well regulated legally.”
– Building Appraiser 1

OPPORTUNITY COST AND LENDING CAPACITY

While the concept of façades as a service is still new, many are familiar with leasing. One shared belief amongst nearly all interviewees was therefore that a façade PSS is a good choice for building owners with little capital available to

them. A comparison gets made to household appliances and cars where a client does not have the budget to make the investment at the onset. Achieving more scope with less capital available. Which breaks down in twofold. Firstly, a shift from capital expenditure to operational expenditure. Resulting in secondly, the freeing up of capital or borrowing capacity for alternative investments, the opportunity costs.

While on the outset it seems clear this that this is beneficial to the real estate owner, in reality it is more nuanced. Shifting from CapEx to OpEx is achieved by transitioning to a PSS model, however drawing a bank loan achieves the same result. Effectively spreading the initial investment over a longer period against the added cost of interest on top of the principal. Where they fundamentally differ is that with a bank loan, the building owner will have a highly leveraged asset on their balance sheet. This directly influences their borrowing capacity. While true that the outstanding financial obligation of a PSS contract also negatively affects this capacity, it does so to a far smaller extent. When compared with an unleveraged façade investment, the implementation of a façade PSS frees up more available capital. When compared with a leveraged façade investment, it has negative impact on the borrowing capacity allow for more leveraged alternative investments.

“The financial obligation to the provider hurts far less than drawing a loan for the full capital investment. The lever of not having to make that investment, compared to the alternative investment you can make with that unspent budget, is far greater.” – Financier 1

EXPEDITED RENOVATION AND BENEFITS

The need for renovating the West façade of the CiTG building has been acknowledged, and so is the added value of a circular façade. But finance department is still reluctant to accept the monetary value of user comfort.

“In the calculation it was of course relevant elements but, in my opinion, they were searching for a bit far-fetched argument as to why it would be better than conventional. Because, sickness absenteeism could be lowered for example, which I find very difficult to see the causal relation. And the energy bill would drastically decrease, but that would be also the case with a traditional façade”
– Real Estate Owner 1

Even if they were to accept is their view is that the energetic performance gains, reduction in operational carbon emissions, the indoor climate and user satisfaction are all inherently linked to the façade itself, these metrics become obsolete. Resulting in the comparison being made between exactly the same façade with different procurement methods. This does not however undermine their potential benefit.

“It are most certainly factors (energy consumption and carbon emission) that should be taken into consideration during the decision making. The most important part is however is whether a building is still in line with the primary function of education and research”
– Real Estate Owner 1

Multiple (semi-) public real estate owners identify the lack of initial capital as a barrier for deep energy retrofits. While simultaneously acknowledging the dire need for large scale portfolio renovation. There are various reasons for not prioritising these types of renovations. Such as the as focussing on (ultra) sustainable landmark developments, overspending on other projects and expansion ambitions. All the while neglecting their current portfolio, and with that

their primary function in these buildings. Indoor climate has been described as uncomfortable and energetic performance is poor. An expedited renovation through a façade PSS offers substantial additional yearly gains for each year the renovation has been brought forward.

“We are expecting our income sources to get smaller all while we have a strategy plan towards 2035 (due to the political landscape). For these projects investment budget had been allocated however we are now noticing that everything needs to go past the board of directors again and that a lot gets put on hold” – Real Estate Owner 2

ORGANISATION STRUCTURE AND DECISION HIERARCHY IMPLEMENTATION OF STRATEGY

For the TU Delft as a customer, a prudential trade-off between the options of 'lease' or purchase is still an important issue. In the previous assessment five years ago, it was not economically sound to rent/lease. The current sentiment at the finance department is that if they have access to treasury banking, at a 3% interest rate, and commercial parties against double that, then it will be more favourable to purchase than to rent. However, they also state that their role is to assess the investment decisions, using the treasury statute but also the campus strategy and the project budget. An increased ambition regarding flexibility in the campus strategy accompanied with a budget realignment could see a shift in conviction. Although, there might be another underlying problem at hand. As there seems to be a mismatch between ambition and practise. Not always are the most economically sound options chosen. As the finance board is not part of the development process, a(n) (intended) delay in relaying the decisions hampers this decision. Often is it the project developer who makes decisions based on aesthetic appearance, strongly influenced by the architect. Life cycle cost analyses will sometimes be done retrospectively and are not a leading principle in the design phase.

"Big parts within the organisation understand the need for thinking in terms of Lifecycle costing, however in practise there are far too many project managers focussed solely on delivering a construction project, within time and within budget. And far too often based on 'shiny rock'. If the architect decides on a pretty concept and we have made a lifecycle vision calculation of an alternative that performs much better, then that option will just be pushed to the side because they are already in love with the prettier one."
– Life Cycle Vision Expert 1

When the project eventually gets presented to the finance department it becomes political. Rejecting the proposal results in long project delays and incur unwanted costs.

"Well finance who is of course following in that huh who is following who is not at the table in the decision-making. Look at one point, Finance says, you have to give me the pieces and show me that you have made choices, but that choice has already been made. We are already in the next step, is at some point Finance who is going to come after, when they should actually be before? This is the budget, you have to build within that and you have to show me every time, are you within that budget? And, what did you do to stay within the budget and are there variations possible within that budget? And now it's the architect who starts drawing and then we ask, what will it cost? Yes, it will come, it will come, it will come, That's the game being played" – Life Cycle Vision Expert 1

Furthermore, the university uses a fragmented budget structure. Various departments, such as project development, facility management and maintenance have their own allocated budget. Budget overruns in development cause difficulties for other projects on the agenda. Having integrated budgets for each project could result in better consideration of the whole life cycle costs. Even if budgets are managed well, the actual expenditures of the unscheduled maintenance costs are often a black box. Insight into this data has been impossible to obtain and the Multi Year Maintenance Plan does not budget unplanned repairs.

CONCLUSION

The analysis of the Leasegevel 2.0 project and its stakeholders highlighted both opportunities and significant barriers in adopting the Facades-as-a-Service (FaaS) model for the CiTG building's West facade. While the project built on the learnings from the East facade renovation, it faced complex legal, financial, and organisational challenges that hindered its realisation.

The TU Delft identified three substantial barriers. Firstly, the discussion on the topic of financial lease vs operational lease. With their current understanding being that the façade PSS concept falls under the former category and is therefore in conflict with the treasury statutes of the university. Secondly, the impact a façade PSS have, on a portfolio scale, on the lending capacity of the university. As the rijksvastgoed bedrijf claims it will negatively impact their collateral. Thirdly, the economically sound business case, as it is their belief that if they can lend at treasurybanking rate and the supplier at market rate, it is more advantageous to purchase the façade.

In addition to this there is a more organizational barrier. As often the decision making is not in line with the strategy. Facades get selected on their appearance and are heavily influenced by the architect. Often neglecting life cycle cost calculation or doing it retrospectively. Pressuring the finance board with potential delays sees projects realise solutions that are sub-optimal.

Contrasting these barriers are developments from both a legal and an appraisal perspective. Where a legal expert on the topic of as a service product underscores that the façade PSS contract is not classified as a financial lease. Allowing for nuance and debate on the topic. Furthering the legal standing by the introduction of the CiSe platform, providing standardised contracts. Secondly, appraisal value of a

building should not be lower with a façade PSS than with a traditional façade. This is the case as long as the contracts provides enough security to the client, guaranteeing them they will not suddenly be left without a façade on their building.

Lastly, the shift in attitude from the financial sector provides opportunity to implement a first full scale pilot project. Furthermore, it allows for upscaling potential through public banks willing to take over the financing on portfolio scale.

4. FINANCIAL SIMULATION

To gain an understanding of the financial feasibility of the CiTG West case, a financial model was made parallel to the interviews. Through comparative analysis, the model aims to identify emergent or confirm hypothesised drivers and barriers. It explores both the value delivered to a (semi-) public real estate owner from a façade PSS offering and the business case perspective of the PSS supplier. Through this holistic method, bandwidths for soft value metrics can be determined as a requirement for feasibility, if even imperative. It aims to answer the following sub-question:

SQ5: How does the use of façade PSS compare to traditional façade renovation procurement?

The following section will delve deeper into the evaluation methodology, the parameters and assumptions and the findings. It will conclude with a sensitivity analysis.

4.1. METHODOLOGY FOR VALUATION

WHOLE LIFE CYCLE COSTING – CLIENT’S PERSPECTIVE

Azcárate-Aguerre (2019) notes that the “hard” and “soft” monetary values are difficult to portray in traditional Life Cycle Costing (LCC) methodologies. Because of this, a Total Value of Ownership (TVO) and TVO+ were introduced in the form of a Net Present Value calculation. A similar approach was used this time. However, in this research, the Whole Life Cycle Costing (WLC) approach (ISO15686-5, 2017) was adopted.

This research evaluates three renovation scenarios of equal utility: Ciskin full PSS with maintained ownership, Ciskin with standard ownership contract and “Business as Usual”, a traditional non-circular façade and ownership. The selection of these three scenarios has been based on discussions with TU Delft CRE and Alkondor. As there is a consensus on the need for a deep energy façade renovation, however, TU Delft has expressed scepticism on the need and benefit of a PSS contract model.

CASH-FLOW ANALYSIS – SERVICE PROVIDER

Parallel to the WLC calculation, a business model assessment has been made for the PSS provider perspective. To produce a realistic NPV comparison, a comprehensive understanding was needed of the underlying business case, as this is critical in determining the PSS-Service fee offered in the contract, this was done by creating a 3-statement model with an income statement, balance sheet and a cash flow statement. The model was further supported by loan modelling and depreciation and amortisation schedules. Finally, everything was summarised in a DCF-model.

4.2. ASSUMPTIONS AND PARAMETERS

The following part will discuss the assumed values and indices. To do so, first, the boundary conditions will be set.

BOUNDARY CONDITION: TIME

The model spans a period of 60 years and, by doing so, is breaking with traditional DCF models in the real estate sector. These are often set at a maximum of 30-35 years and often even shorter than that. The reason for doing so is that it incorporates the circular qualities without the direct need for a residual value. As 60 years covers two traditional façade lifecycles, it allows for a full replacement of the façade halfway through the model term.

BOUNDARY CONDITION: CITG WEST FAÇADE

The financial model is part of the CiTG West façade case study, and so it is not a direct proxy for all similar projects. The findings can be used for lessons learned, however. One important case-specific parameter is the Weighted Average Cost of Capital (WACC), which is the average cost of debt and equity and has been set at 4% (Interview 3, Finance expert TU Delft). However, an interview with a maintenance and operations advisor of the university indicated that for Life Cycle Vision calculations, they use 2% as the discount rate. Another important assumption is that, for theoretical purposes, the TU Delft draws loans for major renovations. Finally, for this specific project, a research subsidy is available of €200.000 from the nationaal groeifonds (NGF). This is a one-time benefit and is not scalable.

BOUNDARY CONDITION: PSS PROVIDER

From the perspective of the Façade PSS provider, there are some boundary conditions set. Firstly, their model requires that the cash flow is always positive, the provider can't operate at a loss. Secondly, a minimum Debt Service Coverage Ratio (DSCR) of 1,4 is required by the Bank (Bank statement of intent, 2024). Thirdly, there is a maintenance reserve account required to cover all maintenance and major replacement costs. The interest rate on this account influences the service fee required. However, it is also a determinant of risk for the business case. Therefore, it has been set to 0% in the base scenario. Lastly, the model requires a minimum Return on Investment (ROI) of 5% to allow for a reasonable profit margin.

PARAMETERS: GENERAL AND INDICES

The model uses various indices for different elements. This allows the model to showcase various scenarios of uncertain future developments. While general inflation can be volatile on a yearly basis, the average is set at a stable 2 per cent. Regarding the raw aluminium price, there are various forecasts out there, however, to not be overly optimistic, a conservative index rate has been set at 4,2%. Because carbon pricing is still relatively new, there is still uncertainty on the development of such pricing models. This model takes an annual increase of 48%, in line with the expected price increase by 2030 from the introduction of ETS 2.0. After that, it is set equal to the energy price index to negate any unrealistic compounding. Additionally, there are the corporate tax rates and the value-added tax. The table below shows these parameters.

PARAMETER	FUNCTIONAL UNIT	RETROFIT (PSS)	RETROFIT (OWNERSHIP-SERVICE)	RETROFIT (BAU)	SOURCE
CPI index	%	2%	2%	2%	(CBS, 2024)
Energy price index	%	3%	3%	3%	(CBS, 2024)
Aluminium price index	%	4,2%	4,2%	4,2%	(CM group, 2020)
Carbon pricing (ETS)	%	48%	48%	48%	(Homaio, 2024)
Corporate tax rate (high)	%	25,8%	25,8%	25,8%	(Belastingdienst, 2024)
Corporate tax rate (low)	%	19%	19%	19%	(Belastingdienst, 2024)
Threshold low rate	€	200.000	200.000	200.000	(Belastingdienst, 2024)
Value Added Tax (VAT)	%	21%	21%	21%	(Belastingdienst, 2024)

Table 1 General parameters and indices

PARAMETERS: TECHNICAL

The product and case-specific parameters are described below. At the same time, the London metal exchange price for the salvage value of aluminium is around €1,50/Kg. Lastly, the technical asset life has been set to 60 years for both the PSS and Ownership scenario in accordance with the data provided by the fabricator. In the BaU scenario, the façade needs to be replaced entirely after 35 years, as is in line with the Multi-Year Maintenance Plan (MJOP in Dutch) provided by the TU Delft.

PARAMETER	FUNCTIONAL UNIT	RETROFIT (PSS)	RETROFIT (OWNERSHIP - SERVICE)	RETROFIT (BAU)	SOURCE
Gross floor area	m2	66.500	66.500	66.500	(Azcarate-aguerre, 2019)
Surface area	m2	2.655	2.655	2.655	(Alkondor, 2023)
Aluminium	Kg	40.000	40.000	40.000	(Alkondor, 2023)
EPC label	Grade	A	A	A	(Alkondor, 2023)
Technical asset life	Years	60	60	35	(Alkondor, 2023; TU Delft, 2024)

Table 2 Technical parameters

PARAMETERS: FINANCIAL

The model assumes that in the case of the full PSS contract, the façade is financed through a gearing ratio of 65% bank loan, 30% downpayment and 5% share capital. A downpayment is required to make the business case feasible and reduce the monthly payments by the client. The bank loans are against commercial rates for the PSS provider and treasury banking for the TU Delft. Both the gearing ratio and the commercial interest rate have been discussed with people from InvestNL and reflected a realistic scenario. Important to note is that the renovation costs are 10% lower for the BaU scenario. This delta is to account for the additional cost of production for a circular façade and has been decided in coordination with the façade provider. The Cost of the façade is based on the completed leasegevel 1.0 project and has also been confirmed by the façade provider.

PARAMETER	FUNCTIONAL UNIT	RETROFIT (PSS)	RETROFIT (OWNERSHIP - SERVICE)	RETROFIT (BAU)	SOURCE
Facade retrofit cost	€	3.250.000	3.250.000	3.168.000	(Alkondor, 2023)
Loan type	Loan	Annuity	Annuity	Annuity	(InvestNL, 2023)
Loan duration	Years	30	30	30	(InvestNL, 2023)
Interest rate	%	6,00%	2,95%	2,95%	(Alkondor, 2023; Ministerie van Financiën, 2024; TU Delft, 2024)
Salvage value aluminium	€/Kg	1,50	1,50	1,50	(LME, 2024)

Table 3 Financial parameters

PARAMETERS: OPERATIONAL

In the model, there are several operational parameters used. The maintenance fee is based on the maintenance plan provided by the façade fabricator. It consists of cleaning, scheduled and replacement maintenance and general costs such as monitoring of the façade. As this is sensitive data, it is not shown in the table. The service fee covers the major replacement cost of glass and sealing, the sunscreens and the electronic components, as well as the required profit margin for the service provider. The fee is for the majority allocated to a Maintenance reserve account and the residual is used to pay dividends.

The risk premium is calculated over both the maintenance and the service fee. However, it has been set to zero in the base scenario. The total fee is indexed annually with the CPI. Lastly, the primary energy consumption and primary energy reduction are derived from the leasegevel 1.0 project.

PARAMETER	FUNCTIONAL UNIT	RETROFIT (PSS)	RETROFIT (OWNERSHIP - SERVICE)	RETROFIT (BAU)	SOURCE
Maintenance cost	€	in model	in model	in model	(Alkondor, 2023; TU Delft, 2024)
Service cost	€	in model	in model	in model	(Alkondor, 2023; TU Delft, 2024)
Risk premium	%	0%	0-20%	0%	(Interview LCV expert, 2024)
Primary energy reduction	kWh/m2 NFA	-170	-170	-170	(Azcarate-aguerre, 2018)
Energy price	€/kWh	0,33	0,33	0,33	(RVO, 2024)
Operational CO2 emissions reduction	tCO2e	600	600	600	(Azcarate-aguerre, 2018)
Carbon price	€/tCO2e	70	70	70	(Carbon Pricing Dashboard, 2024)

Table 4 Operational parameters

4.3. RESULTS

In the next section, the findings of the financial model will be discussed, considering primarily the TVU / TCO from the client perspective and secondarily the business cases for the PSS provider.

FINDINGS CLIENT PERSPECTIVE

The results show that the net present value of the costs in the BaU scenario is the highest over a period of 60 years, followed by the full Ciskin PSS scenario and finally, the Ciskin traditional procurement with service contract. It becomes clear that the current maintenance strategy, or lack thereof, is undesirable. Having to replace the façade halfway through the 60-year cycle weighs heavy. This is even more so, considering that the aluminium price index is set at a conservative 4,2%. It is expected that commodities like these will get scarcer as the supply chain consists increasingly of non-virgin aluminium.

Early façade replacements could suscept building owners to volatile price surges and unwanted costs, negatively impacting the investment decision. Going for a circular façade with a proactive maintenance structure is the better option.

That the Ciskin traditional procurement is the most favourable is in line with the the comments made by the TU Delft as to why they would purchase the façade themselves against better financing conditions. However, the delta created by the interest rate is relatively small compared to the whole life cycle costs. Furthermore, this scenario is under the assumption that maintenance parties are willing to commit to a long-term maintenance contract for 60 years. Guaranteeing to prolong the technical life of the façade by a traditional cycle (and beyond) with full responsibility is a tall order. To do so with a product from an external party creates even more risks.

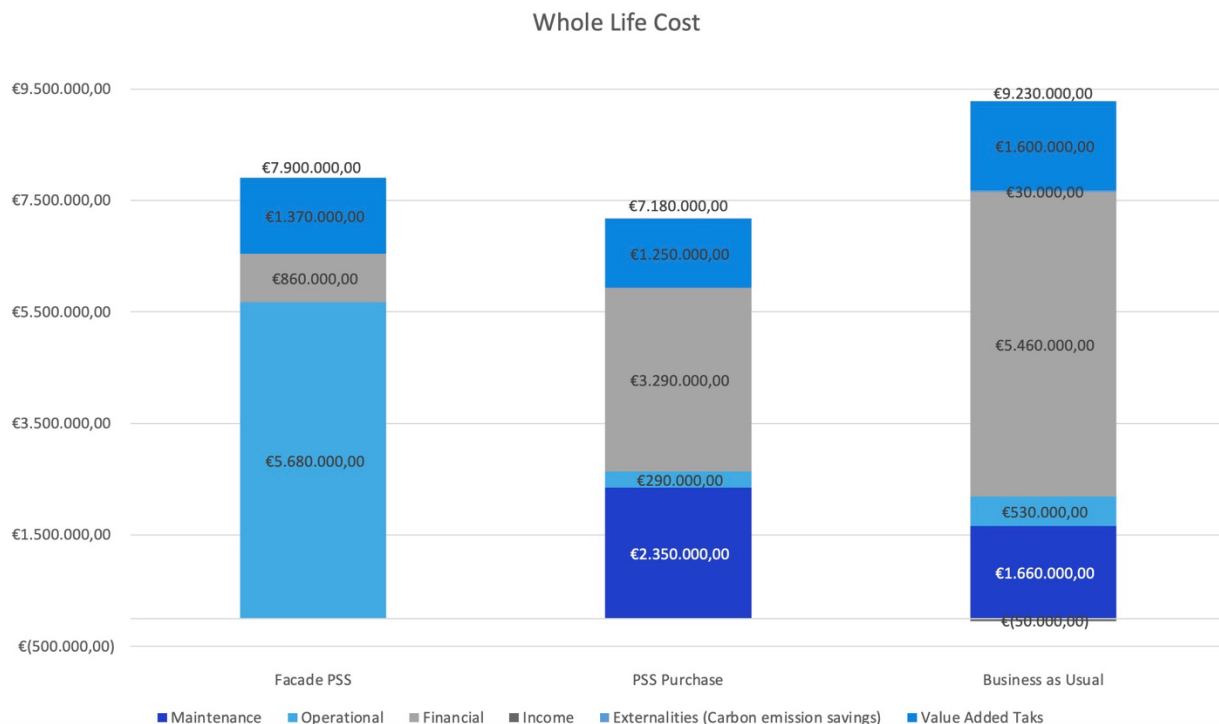


Figure 15 Whole Life Cost calculation (€ in NPV over 60 year period)

If parties are already willing to agree to this, they will likely charge a high premium. This is further advocated by an interview with the maintenance and operations advisor of the TU Delft. *“Can you expect normal price offerings? No, they are going to account for risk. They have to account for quality standards, have repair and maintenance when failures occur and have a product that is not their own, which they do not know what it will do over a 60-year period. So, they will charge a risk premium; this can go up to 1.5 to 2 times the normal rate”*

Such a risk premium could see the PSS contract equal the traditional procurement or even surpass it in favourability.

In addition to this, the added opportunity value of alternative investments discussed in Chapter 3.2 is not shown, nor is the benefit of expedited renovation. For the CiTG case, forwarding the renovation could result in significant energetic gains, around the number of €50.000 per annum. While operational carbon reduction could provide similar savings presently, with the introduction of ETS 2.0, this can go up to €180.000 a year by 2030. The impact will be further discussed in the sensitivity analysis

FINDINGS PSS PROVIDER PERSPECTIVE

The model provided key insights into previously unbeknownst requirements regarding the price point at which the service fee can be set, as well as highlighting the incentive structures, risks and potential financing problems.

Firstly, based on the contractual agreement described in Chapter 3.2, there is a need for the service provider to build up reserve capital to facilitate major replacement costs without relying on additional loans. This effectively results in higher upfront costs for the client, negatively influencing the NPV.

However, this does provide security for both the client and supplier as it ensures both proactive and reactive maintenance will be executed, even in times of financial scrutiny. Whereas in the BaU scenario, a lack of financial means or priorities elsewhere could see maintenance schedules being pushed back, resulting in unwanted deterioration and eventual product failure as a result.

Because of the high financial obligations of the façade provider during the initial loan term, most of the return on their investment will be made over the second half of the 60-year contract, as shown in the figure below. This results in a very strong and substantiated incentive for the service provider to prolong the functional life of the façade way beyond the traditional 30 years. It is at the same time important to note that this requires façade fabricators to break with their traditional revenue structures. The deferred revenue from such a model has significant impacts on the organisation. Façade producers have limited production capacity; therefore, the decision on how to use that capacity is crucial for their company structure. It would require choosing long-term benefits over short-term gains from traditional projects with direct profits. Although façade PSS projects would cover the cost of operations, it would also mean that there is less budget to invest in R&D and company growth.

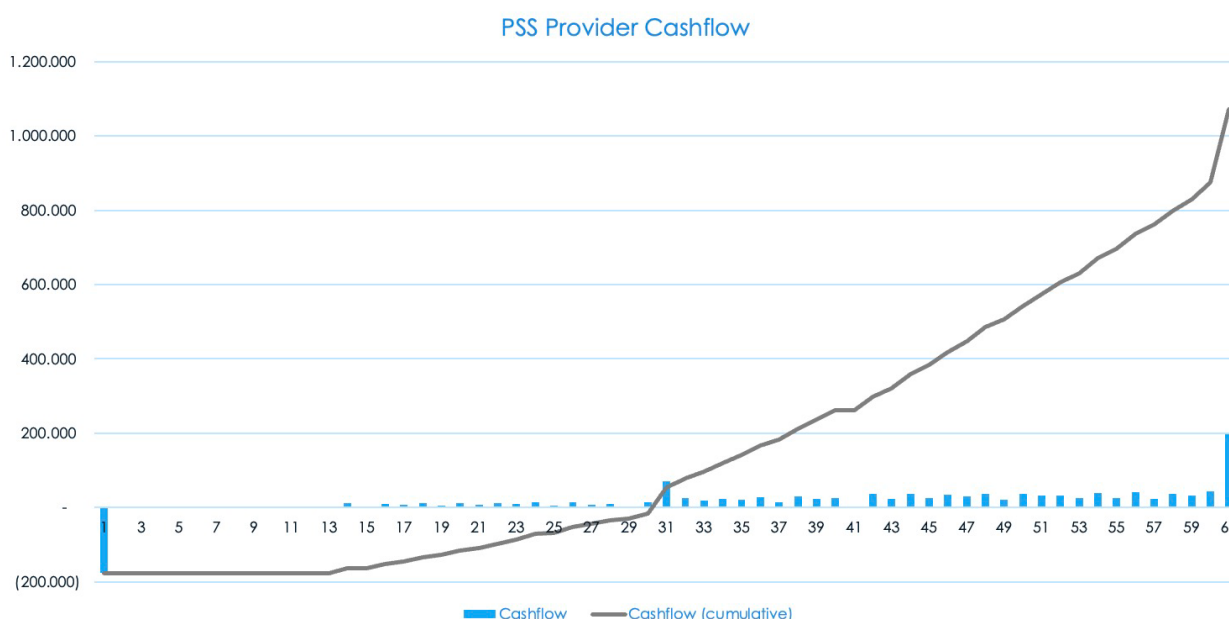


Figure 16 PSS provider cashflow over a 60 year period

4.4. SENSITIVITY ANALYSIS

The sensitivity analysis will explore the parameters that have the biggest impact on the CiTG case study. While the energy pricing indexation, as well as the carbon pricing indexation, will be critical in a comparison set at different starting points in time, they are not, however, for the comparison between equal utility. Therefore, the raw material index of aluminium and the interest rate on the maintenance reserve account have been chosen, as well as the risk premium on the maintenance costs. Lastly, the accelerated renovation speed.

Variable 1: The raw material index of aluminium is tested with the mean index rate set at 4,2% and with a Std deviation of 1,5%. Using the =NORM.INV() function with a random probability provides insight into the effect of material scarcity in future scenarios.

Variable 2: The loan interest rate is looked at in combination with the achievable interest rate on the maintenance reserve account. The former is set at a standard rate of 6% with a Std deviation of 1%, while the maintenance reserve account is set at 2,5% with the same deviation. Through this, insight is created into what would be the best PSS offering possible.

Variable 3: Risk premium on maintenance will provide an understanding of a what threshold the Ciskin PSS will surpass the Ciskin with the traditional procurement and maintenance contract. The base rate is set at 10% with a Standard deviation of 5%. Allowing for high variance as the insights into real market conditions are lacking.

Variable 4: Renovation speed can be one of the most important decision factors for choosing a façade PSS over traditional models. Therefore, the PSS model has three variations.

1 – no accelerated renovation, 2 – renovation is moved up 5 years and 3 – renovation is moved up 10 years. This is an oversimplification as, in reality, the model would need to account for a later start date in the alternative scenarios. However, to gain first insight into the potential benefits gained, both the energy savings and the operational carbon savings have been taken as a reduction on the NPV cost.

RESULTS

The results of the sensitivity simulation show that the ownership model is still, on average, the most favourable when comparing renovations taking place at the same time. Even in the maximum scenario with an additional 26% risk premium on the maintenance fee, it is still competitive with the average of the PSS contract. The non-circular façade highlights the negative impact price volatility can have on backlog maintenance. Because this results in the need for a full replacement of the façade after 35 years. If the raw material index for aluminium goes up to 9,5% then this strategy will bear huge risk moving forward. While in the base scenario, the PSS can outperform the traditional Ownership scenario, it would require the loan interest rate to drop down to 2,0%. This is not realistic. The maximum case in this scenario can be, however, as it is at an interest rate of 8,8%. Not unthinkable under current conditions. Expediting the renovation can have considerable benefits on the investment decision. Considering a 5-year acceleration would see the PSS, on average, outperform the ownership model. This is in the scenario that a 6% loan can be acquired and that the reserve account generates 2,5% interest. Another 5 years would see even more benefits as high energy costs can be saved and carbon emissions can mitigated.

	BaU	OWN	PSS		
Accelerated	0 years	0 years	0 years	5 years	10 years
Max	€ 22.500.000	€ 8.000.000	€ 9.100.000	€ 8.500.000	€ 7.600.000
Mean	€ 9.600.000	€ 7.500.000	€ 7.900.000	€ 7.300.000	€ 6.500.000
Min	€ 6.900.000	€ 7.000.000	€ 6.600.000	€ 6.100.000	€ 5.300.000

TABLE 5 SENSITIVITY ANALYSIS RESULTS (COMPARISON BAU; NON-CIRCULAR FAÇADE WITH TRADITIONAL PROCUREMENT, OWN; CISKIN FAÇADE WITH TRADITIONAL PROCUREMENT, PSS; CISKIN FAÇADE WITH FULL AS A SERVICE CONTRACT)

5. SYNTHESIS

Since the first two iterations of the façade leasing project, several advancements have been made. However, also multiple barriers have not yet been resolved, and some have newly emerged. The next section will discuss, through comparison, the progress made since the leaselevel 1.0 project.

Two of the main barriers at the outset of the leaselevel 1.0 project were the legal and regulatory constraints and the misalignment of liabilities in financing as complexities in contracts and the law of accession had not yet been resolved as well as the high perceived risk by the financial sector leading to an unwillingness to finance. However, since then, the financial sector has undergone a notable attitude shift. With a statement of intent (Appendix X), the sector underscores its ambition of realising circular products like these. Even willing to get involved against cost-covering interest rates to get these types of projects off the ground. Strengthened further by the development of the circular scorecard, an assessment tool for circularity risk assessment in bank investments. This is accompanied by progress made regarding the legal frameworks. Initiatives such as the CiSe platform have been introduced, which made strides in mitigating legal constraints through standardised contracts.

However, from the university's perspective, these developments have not fully tackled the underlying issues. They have acknowledged the beneficial sustainability impacts and improved user performance inherent to façade renovations, and thus the importance of doing such a renovation. However, with this, the lack of valuation standards has not been resolved completely. Some values are considered a bit

far-fetched, such as the decrease in sick leave of employees due to a new façade. They felt it was reaching and that the researchers were looking for ways to make up for an otherwise economically unsound proposal. This research discovers that the values of a façade are not at the core of the discussion when talking about the procurement method. Identical facades allow for these values to be left out of the scope when comparing, focussing only on the differing parameters related to the contract method. One such value is in the maintenance cost, in earlier research presumed to be equal in all scenarios. However, this is an incorrect assumption. Market parties are likely to incorporate a high-risk premium over the maintenance and replacement cost to cover the high uncertainty associated with an unfamiliar product. Unlike façade PSS providers who have a different incentive structure. Because their risk premium is covered by the retained ownership and the associated cash flows generated by utilising the façade multiple cycles.

Furthermore, two of the main barriers from the earlier project have been partially resolved. Both the focus on the initial investment and the short-term investment cycles have improved to a certain extent. As mentioned before, there is a growing understanding within the TU Delft of the need to transition to a circular economy. Resulting in a shift of focus from low, upfront costs to a willingness to pay for more circular products at higher upfront costs. Additionally, while the short-term investment cycles are still in play, there is a willingness to consider longer TCO calculation periods, as is done in the financial model in this research. Projecting the cash flow over a 60-year period allows for long-term benefits from the circularity of the façade.

Both the interviews and the financial model further support the drivers for a façade PSS described in earlier research by Azcárate-Aguerre (2023). The accelerated

renovation proves to be of substantial benefit to the client when considering the energetic performance improvement as well as the operational carbon reduction. The financial model especially confirms the alignment of long-term interest from a façade provider perspective. With most of the profit margin occurring in the second 30-year cycle. As well as the risk of rising material scarcity. With high price inflation of raw materials, the BaU scenario can lead to high unplanned costs. However, the added flexibility of the façade PSS concept seems to be acknowledged at a superficial level. Many of the interviewees do think that flexibility would be beneficial, but when asked how the system could fit into the campus strategy, they were unable to provide any insight.

05 DISCUSSION

The following section will discuss the findings from the empirical research and the literature review. It will consider the meaning and relevance of the results by focussing on explaining and evaluating what was discovered.

ACCELERATED RENOVATION

One of the main drivers suggested both in earlier research and again in this paper is the expedited renovation made possible by implementing a façade PSS. The lack of initial investment allows for investments elsewhere; however, this is more nuanced. The impact of the accelerated renovation is now attributed in full to the façade PSS, but the interviews suggest that the opportunity cost reduction gained from a CapEx to OpEx shift is not zero-sum. This means that if the asset value is not on the books of the client, it does not directly translate to a lending capacity of equal value. The financial obligation associated with the PSS contract has an impact as well. Furthermore, there is a discussion of the portfolio value as collateral, which can potentially negatively influence the lending capacity by implementing the façade as a service concept. Even in the best-case scenario, it is equal to traditional facades as of this moment. In this research, a downpayment was implemented to make the business case feasible and reduce the monthly payments by the client. This further impacts the opportunity cost. The delta between these three factors: the increased lending capacity by offloading the asset, the change in capacity from the portfolio collateral and the downpayment results in a new budget available for expedited renovations.

This delta in lending capacity is lower than the initial capital investment, and thus, an additional budget needs to be acquired for other expedited renovations of either equal or smaller size. The renovations of equal size result in a lower attribution of the environmental and sustainability gains while renovations of a smaller size result in less gains realised.

NEED FOR COMPREHENSIVE IMPACT SCOPE AND TU DELFT'S ROLE

To address these challenges, a better understanding of the potential impact scope is essential. This initiative is beginning with the TUD CRE energy team. This research suggests that the TU Delft adopts a more proactive role in advancing the façade PSS concept. Currently, supplier-driven projects result in incomplete and superficial insights into the added benefits. Many potential advantages are specific to the client's portfolio and strategies, necessitating a clear understanding of renovation challenges and available budgets. Investigating the actual impact of off-the-balance façade systems on borrowing capacity compared to hypothesised reductions from building and portfolio appraisals is crucial. Concrete internal assessments will determine the tangible benefits of such systems.

FINANCIAL CONSIDERATIONS FOR UNIVERSITIES

Universities often need to conserve funds for reinvestment in real estate, aiming to increase equity and liquid assets for future investments. Recently, some institutions have appeared profitable due to the low depreciation of older buildings, leading to higher reported profits allocated for accommodation needs. However, future financial positions are expected to worsen

due to decreased capital and increased reliance on uncertain funding streams. Since 1998, the solvency rate of universities has declined from 63% to 49%, reducing their ability to meet long-term obligations. While borrowing can spread investment costs over time, higher interest expenses without government contributions strain education and research budgets. Increased dependence on uncertain funding sources affects universities' capacity and willingness to make long-term investments (Den Heijer et al., 2016). Therefore, understanding the maximum operational expenditure capacity is essential. Shifting from capital expenditures (capex) to operational expenditures (opex) requires integrated budgets, as operational budgets are also finite.

MAINTENANCE PLANNING AND CIRCULAR FACADES

Inadequate maintenance planning and practices accelerate the deterioration of building performance, leading to premature end-of-service life for buildings and wasted durability (Haagenrud, 2004; Kesik, 2002; Brand, 1994). Haagenrud attributes the poor condition of building stock to the "build and let decay" era of the past thirty years, synonymous with a throwaway society (Patterson, 2017). Neglecting maintenance for curtainwall façade systems beyond routine cleaning can increase operational energy usage, compromise occupant health and comfort, deteriorate interior finishes, damage structural systems, and shorten façade lifespan. Implementing planned repair, maintenance, and retrofitting strategies, along with designs that facilitate these activities, offers significant benefits (Patterson, 2017). However, as façade systems become more sophisticated with greater automation and integration, maintenance and operational challenges emerge. Leveraging specialised expertise for long-term façade system

performance management is not only advantageous but also necessary, especially considering TU Delft's current build and let-decay strategy. If no change in strategy is made in the case of traditional procurement of a circular façade, then material stewardship becomes complicated, and the university becomes susceptible to high unwanted replacement costs.

MARKET EXPLORATION AND CIRCULAR FACADES

The comparison suggested by the TU Delft between the traditional procurement of a circular façade and a full façade PSS contract assumes one of two things. Firstly, the university bears full responsibility and risk for the stewardship of the façade. Secondly, there is the option to outsource the maintenance contract with market parties. As discussed above, it is highly unlikely that, with the current maintenance practices, the university is capable of conserving the full circular potential of the façade. The TU Delft as an organisation lacks the facilities and capabilities to achieve this, and acquiring them would result in additional expenditures, further deviating from the university's core business activities while bearing the full risk of failure. Therefore, it is necessary to inquire with market parties for a 60-year maintenance contract with full responsibility. Such a contract would result in high-risk premiums as they would be reliant on an external party, being the façade provider. As well as not having a clear upside for bearing responsibility, unlike façade PSS providers who retain ownership of the façade. This is understandable as these parties are uncertain whether replacement parts are available or even still in production down the line. Integrated utilities further emphasise this risk and add a degree of complexity to the maintenance of the façade, increasing the premium.

FLEXIBILITY AND TU DELFT'S 2040 VISION

Beyond impact scope, the inherent flexible value of façade PSS is significant. While some research addresses the financial value of flexibility, truly unlocking its potential requires it to become a decisive driver in project developments. Den Heijer et al. (2016) note that numerous uncertainties necessitate flexibility, as various trends outline a difficult-to-predict future. Strongly anticipating a particular future can carry significant risks, such as overinvestment in space with the wrong function, size, or quality of future conditions.

Implementing flexible values is a core principle in TU Delft's transition vision for 2040. The vision emphasises the campus's continuous evolution to meet increasing demands for space in education, research, innovation, business, housing, and facilities. Maintaining quality public spaces while accommodating growth is essential. Compact construction preserves public areas for climate adaptation and tranquil study gardens. Strategic voids and urban planning flexibility are required to facilitate short-term changes, with temporary buildings serving various campus functions like education, startups, hospitality, and housing for students and young researchers. Façade PSS implementations, through their circular nature and durational flexibility, align perfectly with this vision. However, integrating this concept into the entire campus strategy necessitates further exploration. Du Preez et al. (2022) stress the importance of a clear innovation vision for strategic management to guide implementation and outcomes. Without a mandate or vision, innovation projects are likely to fail. Ensuring that innovation projects align with the vision also facilitates resource allocation.

Managerial flexibility, both financially and in human resources, is essential to support innovation initiatives. This underscores the crucial role project managers play in implementing façade PSS concepts and securing favourable support from the finance department.

VALUATION METHODOLOGIES AND LIFE CYCLE COSTING

Contrary to previous research, this study suggests that developing a standardised, comprehensive Total Value of Ownership (TVO) methodology is less of a boundary in itself. While there is a recognised need for further research into the softer values associated with façade renovations, many of these values are inherent to the façade as a product. They are important for contemplating renovation decisions but not necessarily for procurement methodologies. Service contracts, however, offer the opportunity to contextualise added values over time, potentially expediting the realisation of these benefits. Additionally, integrating life cycle costing methodologies into current management practices is essential. Tools like life cycle vision should guide design decisions throughout the development process rather than being applied post-completion. This approach would enable the university to make meaningful progress toward more sustainable practices. Relying on project managers to incorporate valuation assessment tools with many soft, often theoretical, values may lead to reluctance and dismissal.

IMPLEMENTATION CHALLENGES FOR PRODUCT-SERVICE SYSTEMS PROVIDERS

Building on initial research findings, several critical factors influence the successful implementation of the façade Product-Service System (PSS) concept. A significant impact is on the Product-Service Systems Providers themselves. Transitioning to a façade PSS model requires PSSPs to supply not only products but also comprehensive lifecycle management services, including installation, maintenance, and upgrades. This shift necessitates restructuring their business models to accommodate service-oriented offerings, which may involve investing in new service delivery capabilities, training personnel, and developing robust customer relationship management systems. Supplier readiness becomes paramount; suppliers must possess the technical expertise, financial stability, and operational capacity to deliver ongoing services. Evaluating their ability to scale operations, manage service contracts, and maintain quality standards over extended periods is essential to ensure alignment with client expectations and project requirements.

ADDITIONAL FINDINGS

Further analysis reveals that the role of the university extends beyond its immediate campus, positioning it as a pivotal player in societal transitions toward sustainable building practices. While the façade Product-Service System (PSS) concept may present challenges for upscaling directly within the TU Delft campus due to existing infrastructure and operational constraints, its potential impact on housing associations could prove substantial. Housing associations, often constrained by limited financial resources and the need for large-scale renovations, can benefit significantly from the optimisation processes referred to as "optoppen." By focusing on optimising façade

systems, housing associations can achieve considerable cost savings and enhance the energy efficiency of their properties, thereby improving living conditions for residents and reducing environmental footprints.

The university's involvement in developing and refining façade PSS technologies can catalyse broader adoption within the housing sector. Through collaborative research initiatives and partnerships with housing associations, TU Delft can facilitate the transfer of knowledge and best practices, enabling these organisations to implement façade PSS solutions effectively despite their financial limitations. Additionally, by demonstrating successful case studies and providing technical support, the university can help housing associations overcome barriers related to initial investments and operational complexities.

Moreover, the societal impact of optimised façade systems extends beyond financial benefits. Enhanced energy efficiency contributes to broader environmental goals, such as reducing greenhouse gas emissions and promoting sustainability. Improved building performance also leads to better occupant health and comfort, which are critical factors in residential settings. By leveraging its expertise and resources, TU Delft can play a significant role in driving these positive outcomes, thereby reinforcing its commitment to societal well-being and environmental stewardship.

6. LIMITATIONS

Qualitative and quantitative research offer different viewpoints and methods for examining phenomena, each bringing distinct strengths and challenges. Given this, the research has separated the examples of limitations into two categories: qualitative and quantitative. These distinctions allow for a more focused exploration of how each method approaches its limitations.

6.1. QUALITATIVE RESEARCH LIMITATIONS

Qualitative research aims to deeply explore and contextualise phenomena, concentrating on addressing the 'why' and 'how' questions. It is frequently employed to investigate novel or intricate issues, offering comprehensive and detailed insights into participants' experiences, behaviours, and perspectives. However, these advantages also present specific limitations, which are outlined below.

RESEARCHER BIAS

While the researcher purposefully did not position themselves with any of the involved stakeholders to conduct this research to prevent any connotation of bias, it cannot be said that there is none. Logically, there is the ambition to come up with new insight for any given project. Especially with novel concepts like a façade PSS. The research findings have the potential to be groundbreaking. This is further strengthened by the ongoing process in the midst of which the research takes place.

GENERALIZABILITY AND REPLICABILITY

Although the CiTG has proven to be very insightful, it is difficult to take any findings and directly project them onto other (semi-) public real estate owners. As shown in the research, many of the barriers are themselves already subjective as well as that they were specific to the TU Delft. While it is certainly possible and very likely for other universities, it does not mean that these barriers will always be encountered so, to for the drivers. Therefore, other real estate owners should consider the research findings as takeaways and try to apply them to their situation.

Continuing on the trend of subjectivity, many interviews have been done using a structured template, however, while in progress they often went of the path intended. Allowing for free-flowing conversations, but making replicability more difficult. The financial model on the other hand is in its basis reproducible, although several elements are confidential and will not be made public.

LIMITED SCOPE

One of the biggest limitations for this research was the scope. Because of its complex nature it was difficult balancing what would be considered and what not. A lot of elements such as the appraisal impact and the legal implications have been touched upon but are deserving of more in-depth research. So, to are the flexibility potential and the portfolio impact. However, many concept were introduced after the research trajectory was already in place. Additionally, a lack of knowledge on other fields of expertise resulted in a limited scope on those topics. Such as the finance implication, attempting to provide a realistic business case but certainly in need of further development.

TIME CONSTRAINT

Time constraint has been very limiting on not only the scope but also the extensiveness of the research. As the empirical research took place over a period of only 6 months there was not enough time for this research to undertake several interviews with multiple people from different stakeholder perspectives. Therefore, limiting the credence of these findings.

DIFFICULTY IN FINDING RESEARCH PARTICIPANTS

Many of the participants have been selected through snowballing method. This resulted in two problems. Several potential interviewees had been identified too late to still be able to incorporate them in the research. As well as missing out on candidates that were not suggested and not thought of by the researcher before the opportunity window had passed.

6.2. QUANTITATIVE RESEARCH LIMITATIONS

OVER-SIMPLIFICATION

The financial model, although complex and certainly detailed, is inherently an oversimplification. Several assumptions like the payment structure are not in line with real world application of such a model. A financial institution has suggested that for a true business case it should show the model on quarterly basis where the research model implements annual payments. Furthermore, indexations might need to be applied in more detail on sub components. Lastly, several elements are left out such as the fee for the hanging points.

RESOURCE CONSTRAINTS

The model is based on provided data from both the TU Delft and Alkondor, but it is still lacking actual real world data regarding the maintenance costs. Both from the perspective of what it would cost for a full service maintenance contract in the market and from the perspective of realised expenditures not only the MJOP of the university.

06 CONCLUSION

1. CONCLUSION OF THE RESEARCH

This chapter will answer the main research question of the study. It will do so by first delving into the sub-questions and finalising with the main conclusion.

SQ1: WHAT ARE FAÇADE PRODUCT SERVICE SYSTEMS (PSS)?

Façade Product-Service Systems (PSS) are innovative solutions that combine building façade products with a suite of services to deliver desired outcomes for users and building owners. Based on PSS theory, they represent any combination of products and services that together provide the user with an effective solution (Mont, 2004). This concept aligns with the idea that "people do not need walls and windows, but comfortable and energy-efficient indoor environments." In practice, Façade PSS can take various forms: the façade can be sold in combination with supplemental services, leased to a user who utilises it without becoming the owner, or the client can retain ownership while the provider offers full service and maintenance (Tukker, 2004; van Ostaeyen et al., 2013).

Leased Façade PSS, where the façade remains under the ownership of manufacturers or service providers, are considered to have the highest potential for promoting sustainability and circularity. When providers consider their façades as assets rather than goods, they are incentivised to minimise operational costs associated with parts and labour while

maximising the lifespan of their products (van Ostaeyen et al., 2013). Additionally, they are motivated to exploit the residual value of their assets, which often leads to remanufacturing or reusing façade components. Properly configured, Façade PSS can thus decouple economic growth from continued resource consumption and assist the transition from a linear economy to a circular one (Baines & Lightfoot, 2013; Azcárate-Aguerre, 2016).

Alternatively, Façade PSS offerings can involve the client retaining ownership of the façade while entering into comprehensive service agreements with the provider. In this model, the provider is responsible for all aspects of service and maintenance, ensuring the façade operates efficiently throughout its lifecycle. This arrangement allows clients to maintain control over their assets while benefiting from the provider's expertise in maintenance, monitoring, and performance optimisation. Such models can enhance the sustainability of the façade by extending its lifespan and improving its operational efficiency.

However, it is important to recognise that not all Façade PSS are inherently circular or environmentally beneficial (Mont, 2002). If a façade is not designed for disassembly or does not utilise sustainable materials, it still relies on the extraction and processing of raw materials, leading to environmental consequences. A truly circular Façade PSS depends on the cooperation of various stakeholders—including designers, manufacturers, service providers, and clients—to ensure that the system is optimised for sustainability throughout its lifecycle.

By shifting the focus from selling products to providing solutions, Façade PSS models change the incentive structure of suppliers and consumers away from resource consumption and towards revenue models that reward efficient and regenerative use of resources

(Baines & Lightfoot, 2013; Azcárate-Aguerre, 2022a).

SQ2: WHAT ARE THE CURRENT METHODOLOGIES FOR VALUING FAÇADE PSS?

The valuation of façade Product-Service Systems currently relies on several established methodologies, including Life Cycle Costing (LCC), Total Cost of Ownership (TCO), Whole Life Costing (WLC), and Total Value of Ownership (TVO). These methods provide comprehensive frameworks for assessing both the direct and indirect costs associated with façade PSS throughout their lifecycle. Life Cycle Costing and Total Cost of Ownership are the most prevalent approaches, focusing on the initial investment, ongoing capital expenditures, operational and maintenance costs, and eventual decommissioning expenses, typically quantified through Net Present Value (NPV) calculations (van Ostaeyen, 2014; Wynstra et al., 2004; Azcarate-Aguerre et al., 2016).

Whole Life Costing extends the traditional LCC/TCO frameworks by incorporating a broader spectrum of economic, social, and environmental costs and benefits over the entire lifespan of the property. This approach aligns with international standards such as the Norwegian NS 3454 and the UK/Canada BS ISO 15686-5:2008, promoting a more holistic evaluation that includes non-construction costs, financing, business expenses, and external social and environmental impacts (Konstantinos, 2013).

Total Value of Ownership further enhances valuation by integrating both tangible and intangible factors, such as energy savings, enhanced user comfort, reduced facility management workloads, increased property value, and environmental benefits like greenhouse gas reductions. TVO not only aggregates all costs but also offsets them with

the anticipated benefits, providing a more comprehensive valuation that supports informed investment decisions (Azcarate-Aguerre et al., 2016).

A pivotal element in understanding and applying these valuation methodologies is the value framework of den Heijer (2013). Den Heijer identifies four types of performance criteria—strategic, financial, functional, and energy value—that organisations in corporate and public real estate management prioritise. This framework aligns closely with den Ouden's (2012) four levels of value: user, organisation, ecosystem, and societal. By contextualising the value chain within the built environment, den Heijer's framework ensures that valuation methods like LCC, TCO, WLC, and TVO are applied in a balanced manner, considering strategic and operational perspectives alongside economic and non-economic values.

Den Heijer's framework is crucial as it bridges the gap between traditional cost-focused methodologies and the multifaceted nature of value in façade PSS. It emphasises the necessity of balancing different types of values in decision-making processes, ensuring that investments in façade PSS are not only economically viable but also socially and environmentally responsible. This holistic approach is essential for fostering sustainable and value-driven innovations in the built environment, where the interests of users, organisations, ecosystems, and society must be harmoniously integrated.

SQ3: WHAT ARE THE DRIVERS FOR (SEMI-) PUBLIC REAL ESTATE OWNERS TO USE FAÇADE PSS?

The investigation into the adoption of façade Product-Service Systems by (semi-) public real estate owners underscores a complex interplay of financial, operational, and sustainability-driven factors that collectively motivate their implementation. A principal driver is the reduction of upfront capital expenditures (CapEx) through the PSS model, which reallocates financial resources from initial investments to operational expenditures (OpEx). This financial restructuring not only alleviates immediate budgetary constraints but also liberates capital, enabling accelerated renovation projects. The expedited renovation process is crucial as it allows clients to swiftly realise significant energy and sustainability benefits alongside enhanced user comfort. By implementing façade PSS, real estate owners can access these vital improvements earlier, thereby maximising the operational and environmental advantages within shorter timeframes.

Furthermore, façade PSS contribute to improved energy efficiency and sustainability performance through the integration monitoring of advanced technologies such as night cooling and automated sun-shading systems. These enhancements lead to substantial reductions in energy consumption and carbon emissions, aligning with environmental regulations and sustainability objectives. The resultant improvements in user comfort—achieved through optimised natural ventilation, temperature control, and lighting—enhance occupant satisfaction and productivity, reinforcing the functional and aesthetic value of public and semi-public buildings.

An anticipated concern regarding the appraisal of properties utilizing façade PSS was initially

expected to negatively impact property valuations due to the shift from ownership to a service-based model. However, emerging insights suggest that the impact on appraisals may be neutral as long as contractual agreements are made to mitigate the risk of a façade-less building. This would mitigate the negative impact on the borrowing capacity of the client and further substantiate the potential to accelerate the portfolio renovation speed. While enhanced building performance and sustainability credentials afforded by façade, PSS can potentially offset any perceived drawbacks associated with non-traditional ownership structures, as of now they are not yet considered in the appraisal the property's market value.

The strategic flexibility offered by façade PSS emerges as another driver. Rather than being pursued as standalone targets, façade PSS possess the potential to be seamlessly integrated into broader strategic frameworks for building management and development. This integration allows real estate owners to adapt their properties in response to evolving technological advancements and shifting organisational needs, ensuring long-term relevance and functionality. The modular and adaptable nature of façade PSS supports a proactive approach to building management, facilitating continuous improvements and minimizing the need for extensive future modifications.

Finally, the newfound willingness of financial institutions to support innovative financing models tailored to sustainability initiatives plays a pivotal role in promoting the adoption of façade PSS. Specialised financial products and partnerships that prioritise sustainability make funding more accessible and cost-effective, thereby lowering barriers to adoption. Involving social banks like the waterschapsbank at big portfolio scale could reduce the interest rates

further making the value proposition very appealing.

SQ4: WHAT CHALLENGES DO ((SEMI-) PUBLIC) REAL ESTATE OWNERS FACE WHEN USING FAÇADE PSS?

The adoption of façade Product-Service Systems (PSS) by (semi-)public real estate owners holds significant promise for enhancing building performance, sustainability, and user comfort. However, this innovative approach is accompanied by a series of substantial challenges that must be meticulously addressed to ensure successful implementation. This research has identified key obstacles that hinder the widespread adoption of façade PSS within the public and semi-public sectors.

A primary challenge lies in the persistent ambiguity surrounding the legal classification of leases associated with façade PSS. There remains no consensus on whether these arrangements should be categorised as financial leases or operational leases. This lack of clarity complicates contractual negotiations and risk allocations between real estate owners and service providers. Financial leases typically imply ownership transfer and greater financial obligations for the lessee, whereas operational leases resemble traditional rental agreements with fewer long-term commitments. The absence of a clear legal framework creates uncertainty, deterring both parties from committing to façade PSS contracts and hindering the establishment of standardised practices within the industry.

Compounding this legal uncertainty is the unresolved issue of property appraisal and its subsequent impact on borrowing capacity. Traditionally, property appraisals are based on tangible assets and their inherent values. However, façade PSS introduce a novel element where the facade is retained by the service provider rather than owned outright by the real

estate owner. Initially, there was a prevalent belief that such arrangements would negatively affect property valuations due to the shift from asset ownership to a service-based model. Emerging perspectives, however, suggest that the impact on appraisals may be neutral or even positive, contingent upon the enhanced building performance and sustainability credentials provided by façade PSS. Despite this evolving outlook, the lack of standardised appraisal methodologies that accurately account for the benefits and structural changes introduced by façade PSS continues to pose a significant barrier. Without consensus on how these systems influence property valuations, real estate owners remain hesitant to adopt façade PSS, fearing potential adverse effects on their borrowing capacity and overall financial stability.

Another critical challenge pertains to the roles of project managers and architects in the implementation of façade PSS. Project managers are often tasked with balancing budgetary constraints and meeting project deadlines while ensuring the seamless integration of advanced façade technologies. Their ability to coordinate among diverse stakeholders, including service providers, financial institutions, and regulatory bodies, is crucial. However, fragmented decision-making processes and potential misalignments of priorities can lead to project delays and increased costs, undermining the feasibility of façade PSS projects.

Architects, on the other hand, play a pivotal role in construction projects. Their focus often leans towards achieving the most visually appealing designs, sometimes at the expense of optimizing the total cost of ownership (TCO). This emphasis on aesthetics can result in designs that prioritise short-term visual impact over long-term financial and operational efficiency. Furthermore, architects frequently exert significant influence over project

managers, potentially steering projects away from financially favorable decisions in favor of more visually driven outcomes. To mitigate this challenge, it is essential to cultivate a strong, integrated vision for the implementation of façade PSS that aligns aesthetic goals with financial and sustainability objectives. Such a vision can guide architects and project managers towards solutions that harmonise beauty with economic and environmental performance, ensuring that façade PSS deliver comprehensive value.

SQ5: HOW DOES THE USE OF FAÇADE PSS COMPARE TO TRADITIONAL FAÇADE RENOVATION PROCUREMENT?

The comparison between façade Product-Service Systems (PSS) and traditional façade renovation procurement reveals significant advantages and challenges from both client and provider perspectives, underscored by a comprehensive sensitivity analysis. From the client's standpoint, the net present value (NPV) analysis over a 60-year period initially shows traditional procurement with a service contract as the most financially favorable option, followed by the full Ciskin PSS scenario, and finally the Business as Usual (BaU) scenario, which presents the lowest NPV.

In contrast, the PSS approach promotes a circular façade coupled with proactive maintenance strategies, which effectively reduce the need for early replacements and shield building owners from the risks associated with material scarcity and price fluctuations. While the initial NPV for PSS may be lower than that of traditional procurement, the inclusion of risk premiums in long term maintenance contracts—potentially increasing costs by 1.5 to 2 times—can make PSS contracts equally or even more favorable. Moreover, PSS offers additional benefits not fully captured in the initial

financial analysis, such as the opportunity costs from alternative investments and significant gains from expedited renovations, including energy savings and reduced carbon emissions.

From the provider's perspective, the PSS model requires façade providers to build reserve capital for major replacements, resulting in higher upfront costs for clients and a lower initial NPV. However, this model ensures reliable and continuous maintenance over the contract period, providing security and fostering a long-term commitment to façade longevity and sustainability. The shift from immediate revenue streams to deferred revenue poses challenges for façade producers, particularly in terms of production capacity, research and development, and company growth. Nevertheless, the long-term incentives align providers with the goal of extending the functional life of façades beyond traditional cycles, promoting sustainability and resilience.

The sensitivity analysis further highlights the robustness of the PSS model under various conditions. PSS becomes increasingly attractive when lower interest rates are made available and when renovation timelines are accelerated, leveraging energy efficiency and carbon emission reductions to enhance overall investment value. Factors such as raw material index volatility significantly impact the feasibility of traditional procurement, whereas PSS models better manage these risks through their proactive and circular strategies.

In conclusion, façade PSS present a compelling and competitive alternative to traditional façade renovation procurement, especially in contexts that prioritise long-term sustainability, proactive maintenance, and accelerated renovation schedules. While traditional procurement may appear more financially advantageous based on initial NPV calculations, the comprehensive benefits of PSS in lifecycle cost management, risk mitigation, and sustainability make it a more

resilient and financially sound investment option. Therefore, adopting façade PSS can lead to more robust and future-proof investment decisions compared to conventional procurement methods.

“HOW DO FAÇADE PRODUCT SERVICE SYSTEMS (PSS) OFFER VALUE TO (SEMI-PUBLIC) REAL ESTATE OWNERS?”

As the Netherlands intensifies its pursuit of a circular economy by 2050, (semi-)public real estate owners are increasingly compelled to adopt innovative solutions to enhance the sustainability, performance, and resilience of their building portfolios. Façade Product-Service Systems emerge as a transformative approach, offering multifaceted value that not only addresses external financial and environmental objectives but also drives internal organizational introspection and restructuring.

Façade PSS primarily deliver value by reducing upfront capital expenditures and positively impacting the solvency of real estate owners. By shifting financial obligations from substantial initial investments to manageable operational expenditures, façade PSS enable (semi-)public entities to preserve their capital reserves and enhance cash flow predictability. This financial flexibility is particularly advantageous for organizations with constrained budgets, allowing them to undertake necessary renovations without compromising other critical investments. The reallocation of financial resources facilitates accelerated renovation projects, enabling real estate owners to implement upgrades more swiftly. Consequently, buildings achieve improved energy efficiency and sustainability performance earlier, alongside enhanced user comfort,

thereby delivering immediate operational and environmental benefits.

Moreover, the integration of advanced façade technologies through PSS significantly boosts the energetic and sustainability performance of buildings. Systems such as Building-Integrated Photovoltaics (BiPV), automated sun-shading, and decentralised ventilation contribute to substantial reductions in energy consumption and carbon emissions. These enhancements not only lower long-term operational costs but also align with stringent environmental regulations and sustainability goals, fostering long-term value creation and regulatory compliance. Enhanced energy efficiency also increases the marketability and desirability of properties, making them more attractive to stakeholders who prioritise sustainability.

User comfort is another critical dimension where façade PSS offer substantial benefits. Advanced façade technologies optimise natural ventilation, temperature regulation, and lighting, creating a more comfortable and productive indoor environment. Increased occupant satisfaction and productivity are essential for the functionality and attractiveness of public and semi-public buildings. By prioritizing user-centric design, façade PSS ensure that buildings remain conducive to their intended uses, thereby reinforcing their value to stakeholders.

A pivotal aspect of the value offered by façade PSS lies in their ability to drive internal organizational changes within (semi-)public real estate owners. The adoption of PSS models necessitates a revaluation of internal processes, budgeting strategies, and maintenance planning. Real estate owners are prompted to shift from traditional CapEx-focused budgeting to a more integrated OpEx approach, fostering a holistic view of life cycle costs. This shift encourages organizations to adopt comprehensive life cycle costing methodologies that account for both "hard" financial metrics and

"soft" value elements such as user comfort and sustainability performance.

Furthermore, façade PSS compel (semi-)public real estate owners to enhance their internal coordination and strategic planning. The need to manage complex service contracts and maintain strong relationships with service providers requires improved interdisciplinary collaboration among departments such as finance, maintenance, project management, and facilities management. This internal alignment is crucial for optimizing the benefits of façade PSS, ensuring that financial, operational, and sustainability goals are harmoniously integrated into the organization's overarching strategy.

Additionally, the strategic flexibility offered by façade PSS encourages real estate owners to adopt more adaptive and forward-thinking management practices. The modular and adaptable nature of PSS allows buildings to evolve in response to technological advancements and changing organizational needs, ensuring long-term relevance and functionality. This adaptability reduces the need for extensive future modifications, thereby preserving the building's value and minimizing disruptions to operations.

However, the transition to façade PSS is not without its challenges. The lack of consensus on the legal classification of leases—whether as financial leases or operational leases—creates uncertainty in contractual negotiations and financial planning. Additionally, unresolved issues related to property appraisal and their impact on borrowing capacity pose significant barriers. The traditional appraisal methodologies may not adequately capture the enhanced building performance and sustainability credentials provided by façade PSS, leading to hesitancy among real estate owners to adopt these systems due to fears of potential adverse effects on their financial standing.

Moreover, the roles of project managers and architects present additional challenges. Architects often prioritise achieving the most aesthetically pleasing designs, sometimes at the expense of optimizing the total cost of ownership (TCO). This aesthetic focus can heavily influence project managers, leading to decisions that favour visual appeal over financial and operational efficiency. To mitigate this, fostering a strong, integrated vision for the implementation of façade PSS that harmonises aesthetic goals with financial and sustainability objectives is essential. Such a vision can guide architects and project managers toward solutions that balance beauty with economic and environmental performance, ensuring comprehensive value delivery.

In summary, façade PSS offer a robust and comprehensive value proposition for (semi-)public real estate owners by addressing financial constraints, enabling accelerated renovations, enhancing energy and sustainability performance, and improving user comfort. Importantly, façade PSS drive internal organizational introspection and restructuring, fostering integrated budgeting, strategic planning, and interdisciplinary collaboration. Despite the significant benefits, overcoming challenges related to legal frameworks, property appraisal methodologies, stakeholder roles, and supply chain complexities is essential. Through collaborative efforts among policymakers, financial institutions, architects, and industry stakeholders, these barriers can be mitigated, unlocking the full potential of façade PSS. Consequently, façade PSS can play a crucial role in creating a more sustainable, economically resilient, and user-centric built environment within the public and semi-public real estate sectors, aligning with the national vision for a circular economy.

2. RECOMMENDATIONS

The following section discusses the recommendations for follow-up actions that can be done to further the façade PSS concept. Afterwards suggestions are made for further research. These are topics that fell outside of the scope of this research but are considered influential in the realisation of the concept.

2.1. ACTIONS

ASSESS MAINTENANCE AND OPERATION CAPABILITIES

If the university decides it wants to continue with traditional façade procurement of circular facades, then it needs to break with the “build and let decay” strategy”. It is, therefore advised to assess their maintenance and operation capabilities. The TU Delft can conduct a comprehensive audit of current maintenance practices and operational procedures for façade systems to identify any gaps and inefficiencies. Implementing planned maintenance strategies is essential; this involves developing and adopting scheduled repair, maintenance, and retrofitting plans to enhance the longevity and performance of façades. Additionally, leveraging specialised expertise by hiring or training personnel with advanced knowledge of façade systems will ensure consistent and effective maintenance practices.

TALK TO MAINTENANCE PARTIES

Engaging with maintenance parties is crucial for determining the true costs of long-term maintenance contracts with full responsibility for the maintenance party. It is important to define clear maintenance responsibilities by establishing well-defined roles and expectations in maintenance agreements to ensure accountability and high-quality service.

CONSIDER THE POTENTIAL SCOPE

When considering the potential scope, the TU Delft should conduct a full portfolio analysis to assess the impact of implementing façade PSS across the entire property portfolio. Looking at the energetic performance and operational carbon impact will determine its scalability. Evaluating the strategic benefits involves identifying how façade PSS aligns with the university’s goals for sustainability, flexibility, and financial resilience. Additionally, understanding upcoming renovation challenges and available budgets is necessary to define the feasible scope for façade PSS implementation, ensuring that projects are both practical and aligned with financial constraints.

GAIN INSIGHT IN THE BORROWING CAPACITY

Gaining insight into the borrowing capacity requires TU Delft to analyse the financial impact of implementing off-balance façade PSS compared to traditional building appraisals. Furthermore, they should look at how it impacts their solvability. This involves investigating how façade PSS affects the university’s borrowing capacity in a concrete manner and assessing the maximum operational budget that can support façade PSS without compromising other financial obligations. Additionally, TU Delft should compare the hypothesised reductions in borrowing capacity against actual financial data to make informed investment decisions, ensuring that financial strategies are robust and sustainable.

INTEGRATE IN STRATEGY

Integrating façade PSS initiatives into the overall strategy is vital for long-term success. TU Delft should align façade PSS projects with its 2040 vision, ensuring they support the campus’s long-term goals for flexibility, sustainability, and strategic growth. Developing a clear innovation vision involves creating a strategic management

framework that includes façade PSS as a key component, guiding its implementation and resource allocation. Finally, fostering managerial flexibility by empowering project managers with the necessary financial and human resources will enable the effective integration of façade PSS into broader campus strategies, ensuring that innovation projects are supported and aligned with the university's strategic objectives.

2.2. FURTHER RESEARCH

Throughout this research many emergent concept came up beyond the scope of this study. Some of which could be crucial for transitioning towards full façade pss systems. Many require the perspective of academics active within their field. The following concepts that need further research al listed below:

IMPACT OF PRODUCT-SERVICE SYSTEMS ON APPRAISAL VALUE

One of the recurring challenges identified in this research is the potential negative impact of facade PSS on building appraisal values. Traditional valuation methods struggle to accurately assess the value of demountable, service-based facades, often resulting in a perceived decrease in collateral value. Future research should focus on developing new appraisal frameworks that account for the circularity and service-based nature of facade systems, as well as their potential to enhance long-term building performance and user comfort.

ALTERNATIVE FINANCING THROUGH GREEN BONDS

The financing of facade PSS models remains a critical barrier, particularly due to high interest rates and limited willingness from commercial lenders to engage with unproven service models. The use of green bonds, which fund environmentally sustainable projects, presents a promising alternative. Further research could investigate the feasibility and structuring of green bonds tailored specifically for facade PSS, examining how this approach might reduce financing costs and align investor interests with sustainability goals.

CONTRACTUAL FRAMEWORKS FOR FACADE PSS

The legal complexities of implementing facade PSS, necessitate a deeper exploration of contractual frameworks. Further developing standardised contracts that clearly delineate ownership, responsibilities, and risk mitigation strategies could help streamline the adoption of facade PSS.

COMPARATIVE ANALYSIS OF MAINTENANCE STRATEGIES

The traditional approach of "build and let decay," where minimal maintenance is performed until significant deterioration occurs, stands in contrast to the proactive maintenance strategies enabled by facade PSS. A comparative study analyzing the actual spending and lifecycle costs of these two approaches could provide valuable insights into the economic and environmental benefits of adopting a PSS model. Such research would help quantify the potential savings and performance improvements offered by proactive, service-based maintenance.

VALUE PROPOSITION OF FACADE PSS FOR HOUSING ASSOCIATIONS

Housing associations typically face budget constraints and have limited capital available for deep renovations. Investigating how facade PSS could offer value to this sector could unlock new opportunities for energy-efficient retrofits and improved living conditions. Future studies should assess the specific needs of housing associations and explore tailored service offerings that align with their financial and operational constraints, potentially creating a new market segment for facade PSS.

IMPACT OF MAINTENANCE ON FACADE DEGRADATION

The relationship between maintenance practices and facade degradation is a critical factor influencing the lifespan and performance of building envelopes. Future research could examine the effects of different maintenance strategies on the rate of facade degradation, providing data-driven insights that support the proactive, performance-based approach of facade PSS. This could help refine maintenance schedules and optimise the service life of facade components.

07 REFLECTION

As I reflect on my research process, I realise that I have been navigating between excitement for the topic and challenges in maintaining momentum. The subject of facades-as-a-service is highly engaging and aligns well with my interests. However, the complexity of the topic, combined with the evolving nature of the research field, left me feeling like I was constantly trying to catch up.

A key element of my approach was action research, which was both effective and difficult to implement. On one hand, it allowed me to actively engage with the material, test ideas, and develop knowledge directly through the research process. On the other hand, this method created tension, as it led to generating insights without always having clear academic sources to substantiate them, which felt conflicting. Despite this challenge, the process allowed for a deeper, practical understanding of the subject matter.

Choosing to conduct a single case study, focusing on the TU Delft CiTG building's West facade, had significant implications for both the scope and depth of this research. While this approach offered distinct advantages in exploring the complexities of facade product service systems (PSS) within a real-world context, it also introduced several limitations that impact the broader application of the findings. The most prominent issue is the limited generalizability of the findings. Insights derived from the TU Delft CiTG building may not apply to other buildings with different design parameters, operational conditions, or financial contexts. The unique characteristics of this building, such as its specific facade design, location, and user needs, limit the ability to

extrapolate findings to broader scenarios. This challenge is particularly significant given the diversity of building typologies and facade systems present in the built environment.

Another critical aspect of my approach was the financial model I developed. This component was successful in terms of providing insight and reinforcing some of my initial hypotheses, such as the potential impact of facade product-service systems (PSS) in accelerating renovation processes. It also highlighted how traditional non-circular facades with a build and let decay maintenance strategy can become extremely costly, particularly in volatile commodity markets. These insights were invaluable in shaping my understanding of the financial implications of facade PSS.

However, the financial model also became a bottleneck in my research. As this was an area where I had limited prior knowledge, I had to invest significant time in self-education, which delayed progress on other fronts. My early focus on the financial dimension prompted feedback from my mentors, who advised me to keep the broader context of the built environment in mind. This feedback was instrumental in shifting my focus. I began to consider the perspective of the building owner more carefully and expanded my approach to include strategic elements, ensuring a more holistic view of the facade PSS's role within the larger framework of the built environment.

When determining the recommendations for follow-up actions and further research, it became apparent the FaaS concept is at a phase where there is a lot of interest in it from both the real estate owner perspective and from the supplier perspective. But both parties need to undergo organisational changes. For public real estate owners, specifically it is necessary to make rigid changes in their maintenance strategies if they want to accommodate the circular economy by themselves. However,

façade PSS offer a solution to this. By outsourcing the responsibilities to external parties, they can focus more on their core business. But this does require organisation wide understanding and compliance. Universities are multifaceted and politically complex institutions. Where, within one party, there are many stakeholders with differing ambitions. Simultaneously, by leaving the ownership of the façade with the supplier, there is a very strong incentive to provide the best care possible. As they need to ensure the longevity of the façade. If we look beyond the start-up phase and take into consideration that we as a society are moving to a circular economy, then it becomes very likely that in the future façade builders are not willing to sell facades to clients anymore. Exclusively offering PSS contracts or only selling the facades at very high premiums. If that is the case it could prove very beneficial to be an early adapter and already build strong supplier relations.

The feedback I received from my mentors was crucial in refining my approach. They helped me recognise when my scope had become too narrowly focused on the financial model and encouraged me to balance this with a broader understanding of the system's impact on the building owner and the built environment as a whole. I took this feedback to heart, adjusting my focus and ensuring that my research focused more on the built environment.

Through this process, I've learned the importance of balancing ambition with feasibility. While my initial approach may not have worked as smoothly as planned, it provided critical learning experiences. The setbacks, especially with managing time and adjusting my scope, have taught me to be flexible and adaptive. I've also learned that self-driven research requires constant reflection and a willingness to pivot, when necessary, which has been key to my

development both as a researcher and as an individual, managing complex challenges.

In conclusion, while my approach, particularly the use of action research and the development of a financial model, had its challenges, it also led to significant insights. The process highlighted areas for improvement but also underscored the value of resilience and adaptability in research. Feedback from my mentors was instrumental in refining my focus, and I have grown both academically and personally through this journey.

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09 APPENDIX