Facades-as-a-Service: Systemic managerial, financial, and governance innovation to enable a circular economy for buildings. Lessons learnt from a full-scale pilot project in the Netherlands

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Facades-as-a-Service: Systemic managerial, financial, and governance innovation to enable a circular economy for buildings. Lessons learnt from a full-scale pilot project in the Netherlands

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Introduction: The challenge of the energy transition in the built environment has, in recent years, been exacerbated by rising awareness of the material resource limitations we face on the path towards sustainable development. In this context the concepts of Circular Economy (CE) and Product-Service Systems (PSS) have emerged as potentially complementary industrial and business strategies to overcome the interdependent material resource and clean energy challenges.

Research significance: Research in the field of circular and PSS-based construction frequently centres on the design and engineering of products, mainly through technical strategies such as design for disassembly and adaptability, and the use of the different "R's" (Reuse, Repair, Remanufacturing, etc.) to extend and/or reset the service lives of building materials and components. Such an approach often ignores the fact that these strategies require changes in the management, financing, and governance aspects of products and therefore buildings, throughout their entire service-lives. This paper will focus on the systemic administrative (i.e. management, financing, and governance) challenges of the circular and servitisation transitions in the building and construction sector, to enable products which are "Circular by Design", to effectively support regenerative processes.

Research question: The paper asks how traditional building products' management, financing, and governance processes prevent or delay the implementation of CE and PSS models. It explores the demand side's perspective (commissioners, building owners and facility managers), taking a systemic view to the search for new practical, strategic, and scalable administrative models.

Methodology: The research method applies the DAS model (De Jonge et al., 2009; Van der Zwart et al., 2009; den Heijer, 2011; den Heijer et al., 2016) to data gathered from focus group discussion and co-design sessions involving multidisciplinary teams of experts from both academy and industry, as well as literature. The research was conducted within the context of the TU Delft Facades-as-a-Service full-scale pilot project.

Results: The research has shown that, while PSS models to enable material circularity can be partially implemented within the current managerial, financial, and governance framework, this implementation is not efficient, effective, or scalable. This is because standard modes of operation in these disciplines are misaligned with that goal. The practical barriers resulting from this misalignment increase the complexity, risk perception, and therefore cost of PSS alternatives, and thus prevent their organic adoption despite increasing market interest. Recommendations are made for policymakers, financiers, suppliers, and building owners to overcome these barriers.

KEYWORDS

product-service systems, circular economy, energy retrofit, building envelope, performance contracting, systemic innovation

1 Introduction

The need for radical systemic change to render the global built environment more resilient and sustainable has been amply recognized for decades. The clean energy transition, rooted in the energy crisis of the early 1970s, has seen a slow and ineffective uptake: the majority of buildings, even in developed countries, still have an energy performance significantly below the desired standard (BPIE, 2011). At the same time, the rate of renovation is consistently below that required to meet climate change mitigation goals established by the Paris Agreement and 2050 climate neutrality targets set by the EC. At the current rate of 1% it will take around 100 years to renovate the European building stock (Artola et al., 2016; European Commission, 2016; Magrini et al., 2020).

This disappointing performance is not the result of technological insufficiency. (Near) Zero-Energy Buildings (NZEBs) use a variety of complex technological components and systems to reduce operational energy consumption, while being able to generate enough renewably sourced energy to offset the remaining need. Rather, it is the result of administrative barriers such as complex decision-making processes, split incentives, lack of access to finance, lack of leadership, and short-terminist thinking (BPIE, 2011; The Economist Intelligence Unit, 2013). The construction and real estate market is, in other words, failing to assign a fair value to climate-change mitigation strategies, or to fairly appraise the risks of non-mitigation.

In addition to the clean energy transition challenge, a new awareness has been growing over the last decades of the interrelated issue of the availability of raw materials needed to deliver and run NZEBs. NZEBs rely not only on the traditional building materials associated with the construction industry (steel, concrete, brick, wood, etc.), but increasingly demand high-value and critical materials such as those found in electric engines, electronic circuits, and renewable power generation and distribution technologies (BIO Intelligence Service, 2013; Fox-Penner, 2014; Abraham, 2015) to meet ever more demanding requirements in terms of energy and environmental performance, health, safety, and comfort. Many of these material elements hadn't been part of the built environment until a few decades ago.

For reasons ranging from dwindling volume of global deposits to increasing difficulty and cost of extraction, or geo-political and financial limitations, access to ever more crucial raw materials is under constant and growing pressure. Rising mainstream awareness of this raw material challenge has recently been exacerbated by noticeable supply-chain crises fuelled by the COVID-19 pandemic and the geopolitical Russo-Ukrainian conflict (World Economic Forum, 2022).

In this context the Circular Economy (CE) has in recent years gained a prominent role in both academic and professional discussions on sustainable and regenerative development. In the construction sector, CE theory aims to address the material challenge presented by the need to meet demands for increasing housing and infrastructure pressure fuelled by a growing global urban population, by the urgent need to renovate the existing building stock, and by rising living standards across the developed and developing worlds, with the imperative of ensuring access to resources for future generations (Behrens et al., 2007; Krausmann et al., 2018).

Product-Service Systems (PSS) have gained increasing traction (Camilleri, 2019) as a potential instrument to enable the Circular Economy transition. This since the redistribution of incentives, responsibilities, and risks proposed by PSS models could support addressing the administrative systemic challenges previously mentioned. PSS is a range of business and industrial models which aim to refocus companies' value proposition from delivering tangible material products towards guaranteeing agreed performance requirements over a defined period of time (Tukker and Tischner, 2006; Stahel, 2010). If the performance requirements include environmental and CE indicators, PSS allow decoupling value-creation from resource consumption while promoting regenerative industrial practices (Fischer et al., 2012; Vezzoli et al., 2017). By doing so PSS creates a financial incentive for more diligent material stewardship (Widmer et al., 2018).

Several research projects have explored the development of PSS for application in the built environment. While frequently initiated from a technology/product manufacturer perspective (i.e. supply push), such initiatives frequently expose the interdisciplinary and cross-stakeholder nature of PSS and CE thinking. A limitation of the studies so far is their theoretical nature. Our research goes beyond what has been done until now by engaging a large consortium around a real full-scale pilot testbed, the "Façades-as-a-Service" (FaaS, a. k.a. Façade Leasing) project. The project has involved building system

TABLE 1 List of factors determinant to the success of a FaaS procurement model[1].

Administrative process	Factor determinant to the success of a FaaS procurement model
Strategic management	Value hierarchy
	Commissioners' organisational structure
	Project briefing
	Contractual organisation (the SPV model)
	Material circularity
Project finance	Financial evaluation of the project
	Transfer tax and Value Added Tax
	Bankability: Impact on underlying cost of capital
	Material markets: The problem of guaranteeing residual value
	Financial evaluation of the project
Governance and building law	Legal framework for value preservation and the argument for concentrated ownership in the real estate sector
	Physical demarcation of materials, components, and systems
	Technical demarcation of performance, responsibilities, and risk
	Risk distribution and bankruptcy law

suppliers, façade fabricator, facility managers, financiers, and real estate developer/operators, supported by multi-disciplinary experts from academy. The aim of FaaS is to test the real life implementation of a PSS for the deep energy renovation of a 3000 m^2 high-end façade of the Civil Engineering and Geo-Sciences (commonly referred to as CiTG after its Dutch acronym) building at TU Delft campus, in the city of Delft, Netherlands.

2 Research question and hypothesis

This paper is the result of a one-decade-long and ongoing research on the implementation path for CE-enabling PSS through the FaaS project, coordinated by TU Delft. The research question behind this paper is to understand how traditional building management, financing, and governance prevent or delay the implementation of CE-enabling PSS models for whole buildings or whole parts of buildings, using the renovation of a high-performance building as a testbed. The hypothesis was that a) current administrative processes (Business as Usual i.e. 'BAU') would hinder PSS by failing to assign a fair value to climate-change mitigation strategies, or to appraise the risks of non-mitigation; and b) a high degree of process customisation would allow the implementation of CE-enabling PSS for the façade in question, but result in a slower, more expensive, and potentially riskier project than its 'BAU' alternative.

3 Materials and methods

Focus-group discussions within previous stages of the FaaS project (Azcarate-Aguerre et al., 2018) led us to identify the key traditional administrative processes and objectively determinant factors to the success of a FaaS procurement model, that need to be addressed to answer our research question and prove our hypothesis, shown in Table 1.

The DAS (Designing an Accommodation Strategy) process model (De Jonge et al., 2009; Van der Zwart et al., 2009; den Heijer, 2011; den Heijer et al., 2016) was applied to the three categories management, finance, and governance to extrapolate actionable lessons from the collaborative strategic learning process of implementing PSS through a cross-sectoral and multi-stakeholder systemic innovation approach. Figure 1 below shows the structure of the DAS method:

Task 1. *Assess the current portfolio: Determine current (mis) match in process and product.*

Task 2. *Explore changing demand: Determine changing strategic and functional, organisational, and societal requirements.*

Task 3. *Generate future models: Weigh and select alternatives.*

Task 4. *Define projects to transform: Detailed attainment plan.*

For this paper, Task 1, Task 2, and Task 3 were used as a basis to structure the collection, analysis and evaluation of the data, while

1 The technological dimension is partially beyond the scope of this paper, and has been described in closer detail in Azcarate-Aguerre et al. (2022). "Facades-as-a-Service: The Role of Technology in the Circular Servitisation of the Building Envelope." Applied Sciences **12**(3): 1267. In the present study technical requirements are discussed as a boundary condition to the decision-making process of other stakeholder disciplines. In a similar manner, financial project evaluation has been expanded upon in a separate publication Azcarate-Aguerre et al. (2022). "Building energy retrofit-as-a-service: a Total Value of Ownership assessment methodology to support whole life-cycle building circularity and decarbonisation." Construction Management and Economics: 1–14. The present paper focuses on the systemic and strategic interaction between different disciplines, and the current real-world constraints which prevent the organic adoption of PSS contracting models in the built environment.

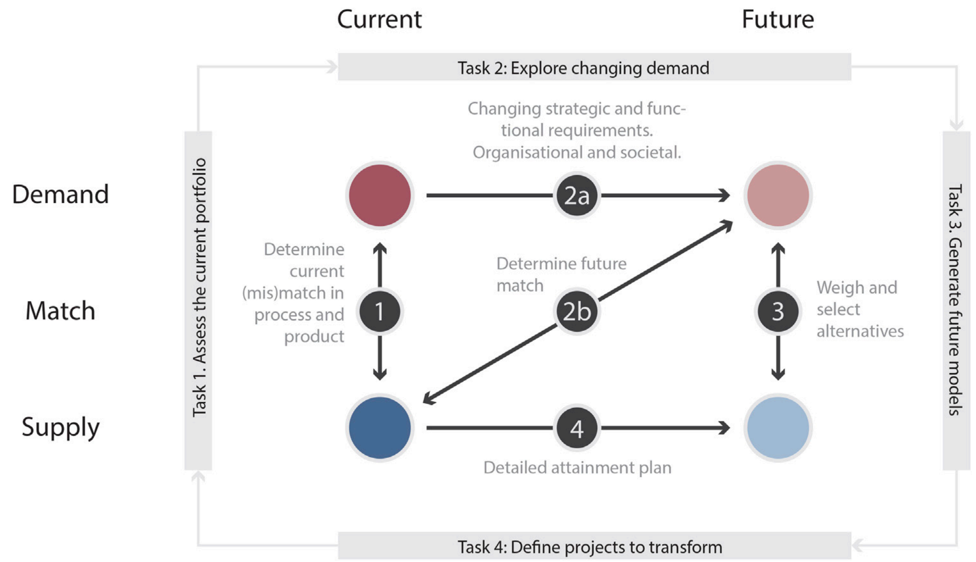

FIGURE 1
Designing an Accommodation Strategy (DAS) in five steps. Adapted from (De Jonge et al., 2009; den Heijer, 2011).

Task 4 is the basis to present and discuss the results and generate recommendations for future developments.

Data for the analysis was collected through empirical evidence gathered from the Facades-as-a-Service (FaaS) project combined with secondary sources. Sources of data include a detailed diary summarising the discussions and outcomes of dozens of co-development meetings between academic and professional experts from different disciplines related to the fields identified above, a record of email threads with attachments, as well as commented legal contracts and other documents related to the most critical discussion points. Lastly, it includes three final reports per year of the project summarising the systemic business model development, the technical execution process, and societal and market dissemination activities (Azcarate-Aguerre et al., 2020; Azcarate-Aguerre et al. 2020; Azcarate-Aguerre et al. 2020). Also in the context of this project a state-of-the-art review was performed on recent and ongoing circular business model research and pilot projects (Vergara d'Alençon et al., 2019).

4 The CiTG pilot project at TU delft (tasks 1–3)

4.1 Task 1: Assess current portfolio determine current (mis)match in process and product

As presented in the Introduction, there is a mismatch between the fact that the product: the building sector, is not contributing enough to the process: climate neutrality and long-term sustainability (resilience) set by and for society. As mentioned, this is evidenced by slow energy renovation rates, leading to high carbon emissions, and no concern for circularity, further increasing emissions and other negative externalities such as pollution, as well as putting at risk the availability of crucial materials and resources for future generations.

The CiTG building selected for the FaaS project exemplifies this mismatch and is thus an appropriate testbed for our analysis. This representative building, constructed during the mid-1960s, displayed many of the performance issues and decision-making challenges common to buildings of that time: its envelope consisted of a painted, uninsulated steel frame with single glazing, and no active ventilation was present in the building. Passive ventilation through manually operable windows in each office space was further hindered when the originally open stairwells had to be enclosed in order to meet new fire-safety standards, thus reducing cross-ventilation and preventing a cooling stack effect through the building. Lastly, an internal and manually operated blind system provided limited prevention to over-heating of the office spaces in the summer, by allowing most of the solar radiation in through the single-glazed façade. As a result, the building consumed large amounts of non-renewably supplied energy and thus did not contribute to climate neutrality goals.

In 2018 the West façade of the building was the target of a minimal maintenance effort which mostly consisted in the repainting of façade frames to prevent their further corrosion and the resulting technical and visual deterioration. This work did not contribute to improving the energy or comfort performance of the building envelope. The main reason provided by decision-makers for the choice of maintenance plan was a 'short available strategic planning horizon', because relevant stakeholders were debating whether the building would be generally decommissioned and replaced within a 10–15-year period. This would represent a violation of the principles of CE, which include applying a hierarchy of "reduce, reuse, remanufacture" to products. The imperative of reducing the use of new raw construction materials, in this case, would have dictated reusing the CiTG building to the fullest extent possible, rather than demolishing it.

TABLE 2 List of functional and strategic requirements for the performance-based renovation of the CiTG East façade.

Requirements	Baseline value (current scenario after minimum maintenance)	Target value (future desired scenario)
Technical readiness		
Energy use (kWh/m^2/year)	214,3	<50
User comfort (Over K hours/year (DIN4108))	>300	<10
Shading system (internal/external, wind-resistance)	Internal blinds	External blinds
Ventilation (manual/automated)	Manual windows	Manual windows + automated night-cooling
Ventilation (passive/active)	Passive	Passive
Technical and user-comfort monitoring	None	Technical + user comfort monitoring
Façade circularity potential	Low-level recycling or landfilling (due to present asbestos)	Full reuse/remanufacturing potential
Strategic management		
Commissioning team structure	Linear (stage)-based	Integrated across all service-life steps
Budget allocation to projects stages	Fragmented budget from diverse departments (development, facility management, end-user, et.)	Integrated budget
Maintenance responsibility costs over following 15–30-year period	Internal (TUD Delft Campus Real Estate)	External (FaaS Provider)
Project finance		
Total Cost of Ownership (compared to baseline)	100%	<120%
Financing	Internal (applied for and served by building owner)	External (applied for and served by FaaS provider)
Cost of capital	−0.5%/year	<1.5%/year
Value of building as collateral	100%	100%
Residual value	Depreciation to zero	Depreciation to 10% of the original cost (indexed to account for inflation)
Governance and building law		
Toxic material liability (Asbestos present in existing façade)	Liability of owner	Liability of FaaS provider
Recovery of material value from existing façade	Asset/Liability of owner	Asset/Liability of FaaS provider
Material recovery (new façade)	Asset/Liability of owner	Asset/Liability of FaaS provider

4.2 Task 2: Explore changing demand: Determine changing strategic and functional, organisational, and societal requirements

In 2019, when the same minimal maintenance work was being planned for the East façade of the building, a consortium of academic and professional experts came together to explore the possibilities of procuring a new façade instead, commissioned through a performance-based contract. Following from research by Den Heijer (den Heijer, 2011; den Heijer, 2013), the research aimed to include the perspectives of as many relevant stakeholders as possible. In particular, the key decision-makers behind the four main value criteria: Strategic management (represented by TUD board of directors and TUD Campus Real Estate (CRE's)'s project development team), Project finance (represented by TUD central corporate finance and TUD CRE's financial department), Technical (represented by a Façade supplier consortium and TUD CRE's project development and facility management teams), and Sustainability performance (represented by Academic advisors and TUD CRE's energy team).

The key performance indicators according to the perspectives of these four target stakeholder groups were summarized into a series of functional and strategic requirements, tangible and intangible, described in Table 2.

The authors of the paper acknowledge that the requirements list is missing critical parameters related to carbon performance. This omission of embodied carbon requirements is due to the lack of broadly recognised methodologies for calculating the embodied carbon of circular technical solutions. Operational carbon requirements are also excluded since they are determined by the building's and the TU Delft campus' central energy systems, which are beyond the scope of the CITG's East façade renovation project.

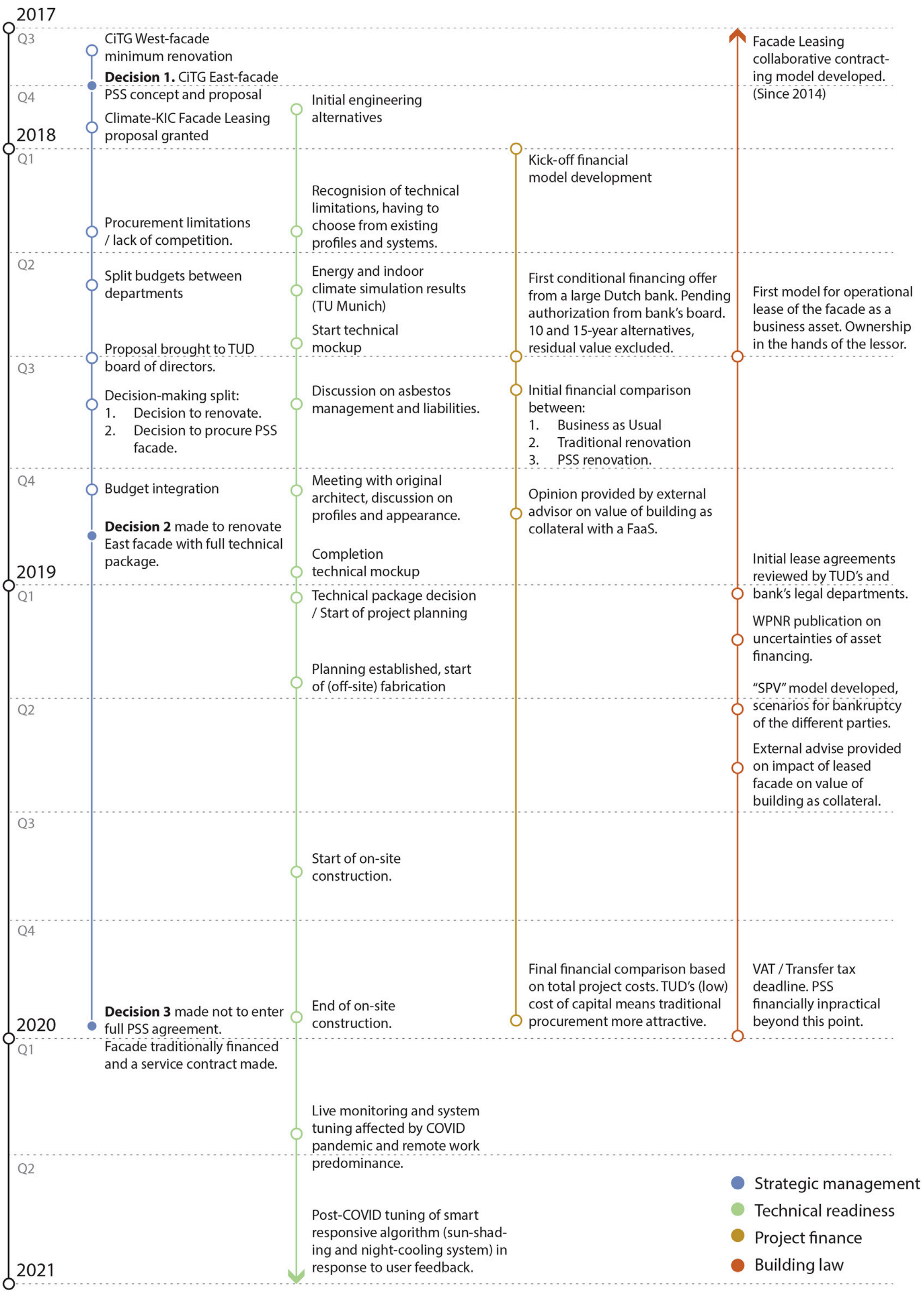

FIGURE 2
Timeline for the CiTG East façade renovation decision-process, and the several multi-disciplinary discussions and milestones contributing to these decisions.

4.3 Task 3: Generating future models: Weigh and select alternatives

In this phase, the multistakeholder consortia led by TU Delft co-designed a feasible decision-making route to decide between a standard and a PSS procurement and contracting models. The decision would have to flow based on the evaluation of each model's costs and uncertainties linked to meeting the requested requirements.

Participating organisations from various fields contributed data on practical experience and expertise for the evaluation of the 'standard' procurement and contracting model, while previous phases of the Facades-as-a-Service project contributed data for the evaluation of the PSS model, albeit on a theoretical basis (Azcarate-Aguerre et al., 2018). These sets of data were used as a basis to design a decision-making process and timeline, structured on the achievement of gradual and specific milestones, from the diverse discipline perspectives, summarized in Figure 2 (Azcarate-Aguerre et al., 2022).

As a result, TU Delft's Campus Real Estate presented the University's Board of Directors, the final decision-maker, with information comparing three scenarios:

- Business as Usual (BAU): A minimum renovation work on the existing East façade, modelled on the works on the West façade procured through a traditional 'linear' purchasing model.
- Traditional baseline renovation: Replacement of the East façade through a traditional 'linear' purchasing model. Some product innovation would be implemented, beyond the technical requirements traditionally established in the procurement process, but no systemic contractual innovation would be implemented.
- Extended FaaS requirements: Replacement of the East façade through a systemically innovative 'circular' PSS model. Technical and organisational innovation would be implemented, beyond the technical requirements traditionally established in the procurement process.

Due to their relatively old and/or heritage building portfolios, retrofit decisions are a challenge common to TUD and other universities. At the time (2020) TUD had to make decisions on the renovation of three of its largest buildings, and resources allocated to these projects in that year's budget was only sufficient for one of them. This illustrates the types of constraints faced even by building owners with relatively extensive resources. Below, we summarize the decision-making process for each scenario.

4.3.1 Decision 1: Business as usual

TUD's Board of Directors recognised the long-term sub-optimal nature of this comparatively inexpensive and fast but underperforming solution. However, on the one hand, a minimum scheduled maintenance could not be put on hold indefinitely while other options were weighted, because corrosion would start affecting the window frames to an irreversible extent. On the other hand, since no energy performance or user comfort improvement was expected from a minimal intervention, there was no pressure from the end-user (the CiTG faculty) to schedule these measures sooner. In fact, the end-user welcomed the opportunity to consider a more extensive renovation project which would contribute to better energy and user comfort performance. If the façade wasn't improved at the time, another 6–10 years would pass before the BAU maintenance had depreciated down to zero, and a decision could once again be considered.

The decision was taken early in the process, In Q4.2017 and even before the project grant had been awarded, to temporarily suspend the planned minimum renovation project on the East façade of the CiTG building.

4.3.2 Decision 2: Traditional baseline renovation

A full decision for a FaaS renovation couldn't yet be taken, as it required further research, but once the BAU scenario was placed on hold, a decision would have to be made on whether the CiTG's East façade would be renovated by Q4.2019, or the BaU scenario would be reinstated to prevent damage to the façade.

The choice was then made to split the decision in two: In Q3.2019 green light was given to the technical CiTG East façade renovation project, so that planning and fabrication could start, and the façade could be replaced between late Q2.2020 and Q4.2020. The decision whether to implement the FaaS model would be delayed until further research was carried out in early 2020.

4.3.3 Decision 3: Extended FaaS model implementation

Once technical decisions had been made and the construction execution process had started, the focus of the project team and the multiple academic and professional advisors could shift towards Task 4, addressing the broader systemic challenges to the FaaS model implementation. Lessons learnt are summarized and presented in the Results section.

Several constraints resulted difficult to overcome, and the final decision was not to enter a full PSS-based FaaS contracting and financing model covering all requirements from Table 1. This as the building owner and not the façade provider is the owner of the façade. Still, a service contract was developed and entered between the building owner and the façade provider. An innovative aspect of this contract is that it is based on the ongoing provision of the Technical and Strategic performance requirements specified in Table 2.

5 Results

5.1 Task 4: Define projects to transform: Detailed attainment plan

In this phase, the consortium set up and defined the proposed FaaS model in terms of its technical, managerial, financial/fiscal, and legal implications. During the co-development process the project consortium aimed to limit as much as possible the number of diverse systemic innovations required for the FaaS model to work. In other words, it attempted to fit performance-based procurement ambitions—to the largest extent possible—within the traditional processes of the real estate and construction sectors. The process and findings from each disciplinary perspective are summarised in the Results section below.

The results of the study (Task 4) are presented below in a summarized form and organised according to the three disciplinary fields previously identified in Table 1. An extended version of these results is provided as additional reference to the reader, in Table 4.

5.2 Strategic management

The lifecycle of a building project - from its initial conceptualisation through its commissioning, operation, and final decommissioning - is guided by traditional and well-established processes which aim to minimise uncertainty and risk. These traditional processes result in systemic inertia across the built environment, resulting in the slow rate of

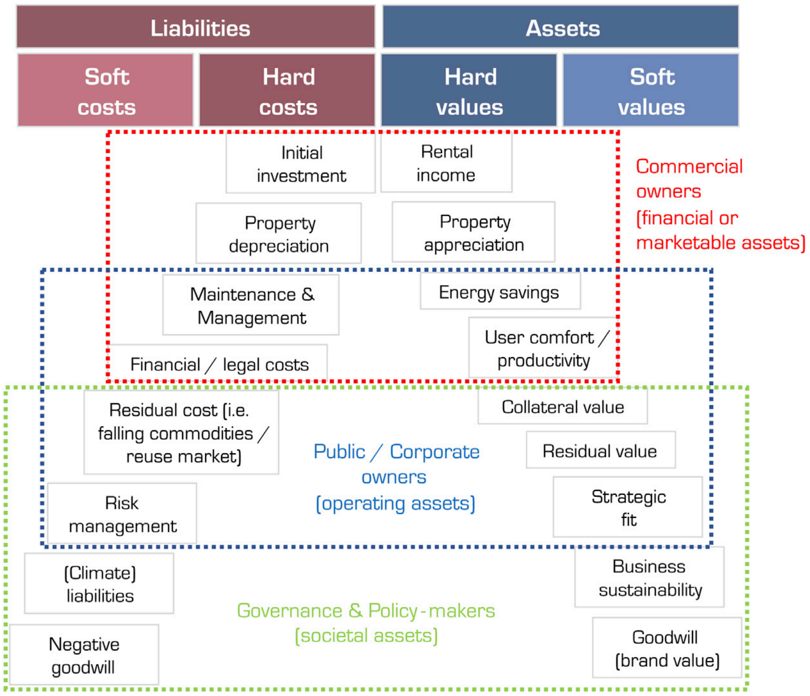

FIGURE 3
Non-exhaustive diagram of soft and hard values and costs in strategic real estate decisions. Highlighted those parameters most relevant to each type of building owner. Adapted from (Azcarate-Aguerre et al., 2022).

change commonly associated with the construction sector. Decisions are constrained to a narrow range due to prescriptive financial evaluation models, organisational structures, and contracting mechanisms.

From the initial planning of a new construction or renovation project, financial feasibility models tend to focus on a specific range of values and liabilities. These as determined by the type and priorities of commissioning organisation (Figure 3). A narrow focus on short-term hard costs and values lead to a wide range of project choices being discarded from an early phase. The lack of standardised and comprehensive Total Value of Ownership models, which include not only short-term, hard values and costs, but also long-term, softer parameters and externalities, distorts the decision-making process in the benefit of well-known and well-tested choices.

Commissioning organisations are likewise organised according to traditional and linear practices. Building projects are frequently transferred from short-term parties responsible for developing and building the project, to long-term parties responsible for operating it. Even in instances when one single organisation is responsible for all phases, as is the case with TU Delft's Campus Real Estate, such organisations are frequently structured according to the same life-cycle stages common among independent parties (Figure 4). This results in a loss of potential knowledge exchange between specialists responsible for the different lifecycle stages, loss of decision-making complexity which would benefit choices with a positive performance over the longer term, while embedding a linear mentality into the construction management process.

The procurement process traditionally focuses on specifying technical solutions, rather than establishing functional requirements. Such a prescriptive approach commoditises system suppliers competing on the basis of lowest price *versus* highest

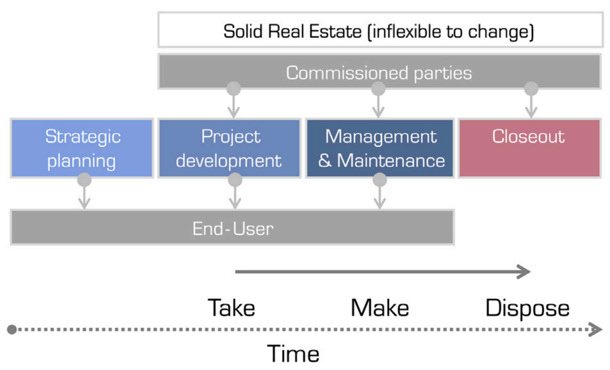

FIGURE 4
Diagram of the "Solid Real Estate" created by development and management organisations with a traditional linear mentality. Even if the same organisation acts as developer, owner/manager, and end-user, the stepped approach to the diverse building life-cycle stages limits strategic knowledge and priority exchange. This in turns limits the chances for innovation in the procurement and management process. Inspired by (den Heijer et al., 2016).

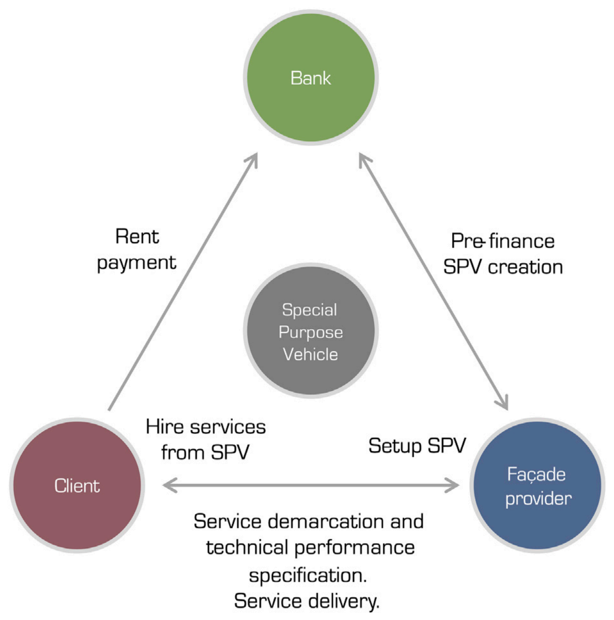

FIGURE 5
Structure for the financing and contractual management of a Façade-as-a-Service, based on a "Special Purpose Vehicle" established by a FaaS developer and possible investor. First published in (Azcarate-Aguerre et al., 2020). In terms of material circularity and the regenerative decommission of building components, the study shows that effective solutions are not yet readily available for either the reprocessing of legacy equipment (reactive circularity), nor for the commissioning on new and effectively circular solutions (proactive circularity). Even commissioners willing to make the additional effort and expense of circular material treatment are most frequently unable to find a second-hand material market and reverse logistics chain capable of handling material recovery from both a technical and administrative perspective.

performance. Long-term performance is frequently beyond the producer responsibility, as is environmentally responsible or circular treatment of material resources. Client organisations (commissioners) therefore assume the risks associated with technical decision-making, component operation, building performance, user satisfaction, and final resource decommissioning and (ideally circular) material treatment.

Contracting models, which are closely related to project finance and bankability, aim to minimise disputes by concentrating ownership. Alternative models for financing and managing PSS alternatives, such as the SPV model illustrated in Figure 5, rely on customized and untested interpretations of building, rental, and property laws. As such they are perceived, from both a legal and financial perspective, as riskier and therefore costlier. The added cost of capital from this perceived novelty and risk result in PSS models being unlikely competitors (from a cost perspective) with more traditional models of direct ownership. This hinders the upscalability of PSS solutions, limiting them only to early adopters with strategic interests and value hierarchies beyond the directly commercial (Figure 3).

5.3 Project finance

Financial performance evaluation of the project was guided by the same procedural constraints identified above and illustrated in Figure 3. The decision-making process was guided by hard costs and values related to capital costs, cleaning and maintenance schedules (internal or externalised in the case of PSS), financial costs and fiscal depreciation. Additional softer values such as expected energy savings and the estimated productivity value of increased user comfort were calculated as a reference, and considered in the decision-making process, but were not prioritised. Residual (circular) value of components was also excluded from the calculation, as none of the involved parties could establish a reliable methodology for assigning a financial value (or cost) to the recovery of materials at the end of the PSS façade's service life.

The results of the financial evaluation process can be found in Figures 6, 7. From a hard value and cost perspective the Business-as-Usual alternative (i.e. not renovating the façade) was calculated to be the most financially attractive (i.e. cheapest) alternative. Only when running

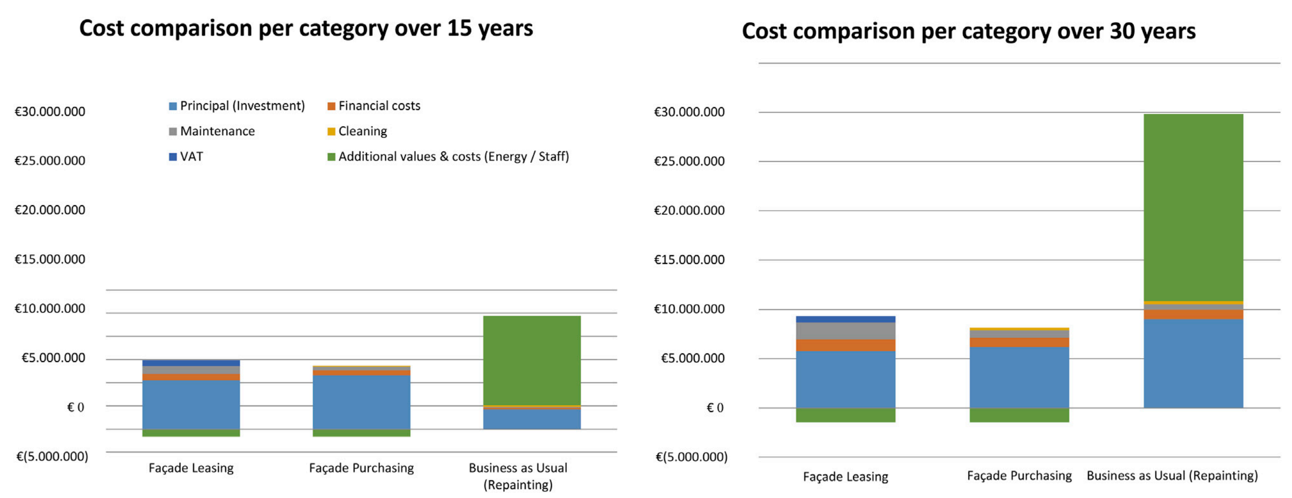

FIGURE 6
Total Value of Ownership results comparing the three strategic scenarios for the CitG East façade renovation, including selected "soft" values, over a 15- and 30-year planning horizon. First published in (Azcarate-Aguerre et al., 2020).

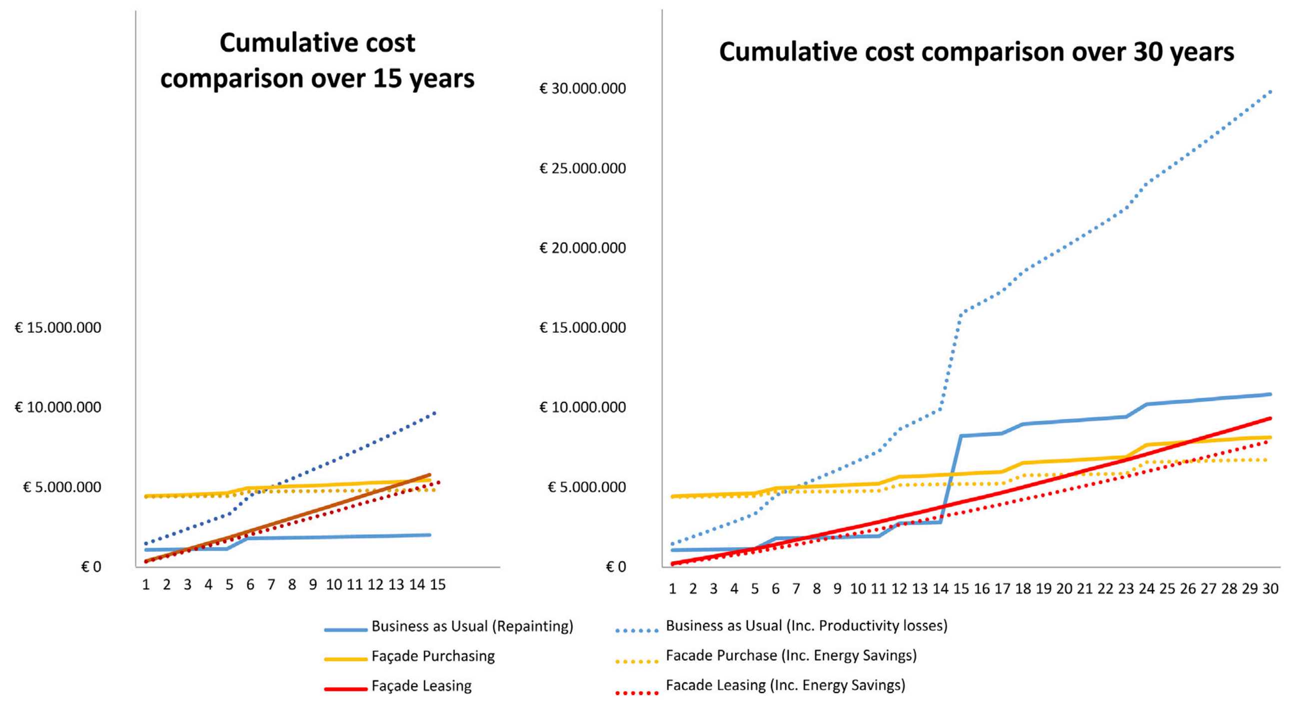

FIGURE 7
Distributed, cumulative Total Value of Ownership results comparing the three strategic scenarios for the CitG East façade renovation, including selected "soft" values. First published in: (Azcarate-Aguerre et al., 2020).

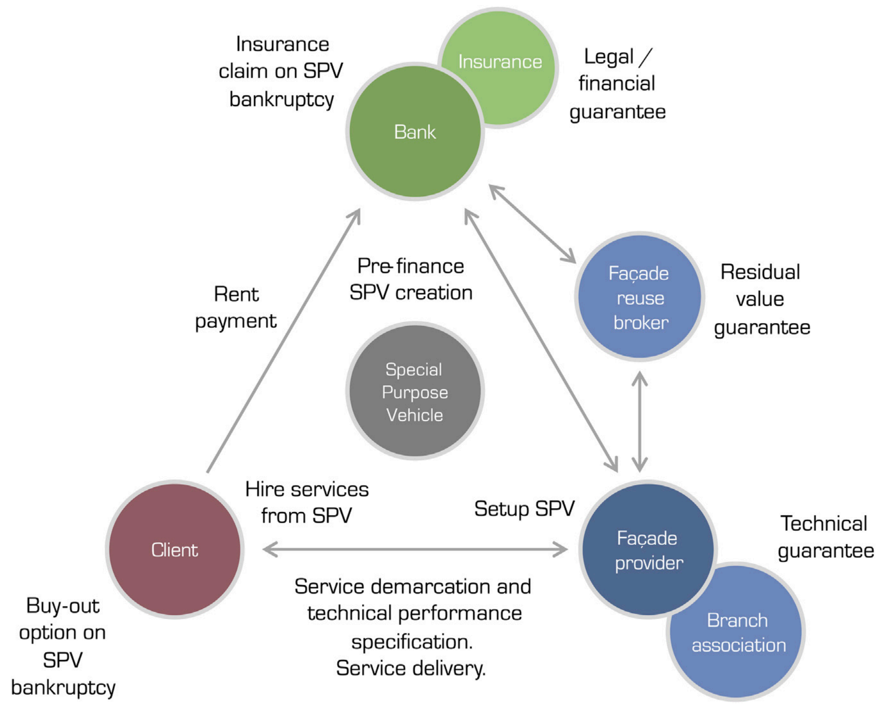

FIGURE 8
Extended structural diagram of the FaaS "SPV" model, showing stakeholders or contractual/financial products intended to guarantee - and therefore reduce the perceived risks and consequential costs of - a FaaS system. First published in (Azcarate-Aguerre et al., 2020).

the calculation over a 30-year planning horizon did this change, as it would be unrealistic to expect the current façade to perform for another 30 years, so that a major renovation would be necessary. Direct purchasing of the façade would be marginally cheaper from a Total Cost of Ownership perspective over 15 or 30 years, but leasing (or PSS contracting) of the façade would result more attractive from a cash-flow perspective. These conclusions are specific to the accountancy practices of the commissioner organisation, and the way in which local fiscal regulation and project finance treat the depreciation of a building asset.

Value Added Tax (VAT) and property transfer tax have a significant impact on the PSS contracting of building components and are the object of some uncertainty due to their fiscal novelty. VAT must be paid by the FaaS owner but can be deducted since the façade is a business operating asset. The building owner, FaaS procurer, will then have to pay VAT on the ongoing monthly service fees. Transfer taxes are likely to result if the façade is transferred (to the SPV or another FaaS-owner entity) after its completion. At the time of the façade construction completion the façade would usually become legal and economic ownership of the building owner, so that its transfer to a third-party entity would result in property transfer taxes. This is unique to each country's tax code, but due to the extensive similarities between tax policies such a transfer tax is expected to result in considerable additional costs and should be considered in the project's financial and fiscal planning.

Bankability of the FaaS alternative is currently a significant challenge. The additional perceived risk of the façade being contractually disconnected from the building results in two financial uncertainties which can carry added capital costs: 1. The financing of the façade is not backed by a complete real estate asset, as would be the case in a traditional mortgage-backed loan. Since the value of the façade, as an independent asset, at any given time is difficult to estimate, the financial construction is backed largely by the solidity of the building owner as FaaS customer. This results in capital costs similar to those of a business loan, and higher than a traditional mortgage-backed loan. 2. The value of the building as collateral, for securing other mortgage-backed loans, might be negatively affected by the "lack" of a legally and economically owned façade. This was a topic of debate, since the loss in collateral value might be counterbalanced by a general increase in the property's value as a result of the new façade and its increased aesthetic, energy-, and comfort-performance.

Lastly but crucially, the difficulty of banking the residual value of materials is a crucial current hurdle to the implementation of PSS or the Circular Economy. The residual value of the FaaS components could not be estimated or considered in the financial evaluation model, and the consulted banks were unwilling to assume any risks related to the residual value of physical components. A more extensive discussion of the rationality behind this barrier can be found in Annex 1: Results (Extended).

2 As a result of the ongoing Dutch housing crisis these values have changed, and exceptions have been created since the period during which the CiTG project was ongoing. These changes are not directly relevant to the present study, but they would influence the extent to which fiscal policy could hinder a FaaS model. Transfer tax is not charged if less than 6 months have passed between a previous ownership change and a new one, in which case the buyer in the second transaction will cover the transfer taxes paid by the buyer in the first transaction. Thus, can double transfer taxation be avoided, but it must be paid when more than 6 months have passed between the first and second transfer.

5.4 Governance and building law

From a policy and legislative perspective, the implementation of PSS contracting models represents a significant change from a *status quo* built on centuries or even millennia of legal precedence. Innovative and relatively untested contracting models result in an added risk to all parties involved in the PSS project. These risks may translate into disputes during the decades-long contracting periods required from built environment technical components, or which may -and currently does—translate into added complexity and cost of financing.

In the case of Netherlands, and many other nations built on Western European and Roman law, the rule of accession gives building owners ownership of all fixtures attached to a building, and which can't be removed without damaging the building or affecting its performance. While several models exist for circumventing this legal barrier, these models are based on innovative interpretations of rental and real estate law, and therefore carry a risk in the case of litigation.

A further challenge, once that of legal and economic ownership of physical components is overcome, is the demarcation of technical and financial responsibility over different building components and the technical requirements they aim to fulfil. Of special concern are physical interphases between components (e.g. the structural brackets linking the façade to the building structure) or between interrelated building services (e.g. the interrelation between building façade and heating or ventilation systems when delivering the final energy and user-comfort performance of the building). In the process of breaking down the building unit into its technical systems and performance attributes a chance for new types of disputes exists, when determining who must bear the technical responsibility and the financial expenses related to it.

In the context of the potential legal and financial disputes discussed above, provisions must be made in advance for the potential exit—willing or unwilling—of one or more of the parties contractually collaborating on the PSS project. Over the 10- to 50-year period which a PSS contract in the built environment might span, innumerable events could occur which would result in the exit of a partner or the reorganization or transfer of part or the whole of the PSS structure. These events include corporate reorganisations, mergers and acquisitions, property transactions, bankruptcy of one or more parties, physical damage to the building by unforeseen events (e.g. natural disasters), market fluctuations resulting in chronical building vacancy, and many others. Different forms of financial insurances or technical/administrative securities provided by, for example, industry branch organisations, must be developed and set in place contractually to deal with such events in the most risk-mitigating manner. Some examples of these securities are illustrated in Figure 8.

A matter of legal consequence which was unfortunately not addressed by the project, but which was frequently discussed during the planning process, is the organization of economically feasible reverse logistics chains for the remanufacturing of used building components. EU regulations are known to limit the cross-border transportation of secondary components, since they are labelled as "waste" which must be treated in its country of origin. This represents a barrier to the economic potential of transporting secondary components to neighbouring EU countries with lower labour costs, where remanufacturing work could more likely be performed in an economically feasible manner.

6 Conclusion

The study set out to test whether the traditional systemic framework for managing, financing, and regulating buildings projects hinder the practical implementation of CE-enabling PSS contracting models. It concludes that, across all the mentioned building-related disciplines, the momentum provided by traditional processes generates a systemic inertia which severely limits the actual decision-making scope of the key stakeholders involved in a construction project. Even in cases in which all stakeholders are aligned from the start in terms of motivations, long-term strategic sustainability goals and willingness to innovate, existing processes largely determine the outcome of financial and fiscal decisions, legal collaboration contracts, building techniques, and managerial organisation. Significant additional effort, motivation, and cost- and risk-bearing is necessary to overcome this inertia. In some cases (such as that of project financing) current practices cannot support competitive PSS alternatives capable of being upscaled to the mainstream construction market. However, the study has also shown that, at least in the case of the Netherlands, conditions enabling a more mainstream implementation of PSS models could be achieved through targeted action in each of the identified disciplinary fields.

Crucially, results have highlighted the interlinked nature of decisions and innovation pathways across involved disciplines and sectors. In several instances, circular arguments spanning across disciplines block progress for the whole industry. This is a clear indication of the need for orchestrating actors whose role is to coordinate multi-lever action at scale.

Table 3 Below summarises results and main recommendations for the three administrative processes addressed by the study: Cells in the column summarizing 'Pathway to systemic innovation towards PSS' have been colour coded to represent a feasibility/readiness assessment according to the following legend.

Conditions enabling a more mainstream implementation of PSS models could be achieved through targeted action
Pathway towards PSS achievable with significant additional effort, motivation, and cost- and risk-bearing to overcome inertia
Current practices cannot support competitive PSS alternatives capable of being upscaled to the mainstream construction market.

TABLE 3 Results summary from the perspective of the three disciplinary fields of study.

Administrative process	Objectively determinant factor to the success of a FaaS procurement model, color coded to represent result assessment from the study	Main recommendation
Strategic management	Value hierarchy	Significant change in organisational strategy, on both the supply and the demand side of the construction sector
	Commissioners' organisational structure	- Supply: Parties interested in the reprocessing must be involved throughout the previous stages of the building´s construction and management to create incentives for resource stewardship or material circularity
	Project briefing	- Demand: Client organisation must develop robust investment models based on comprehensive TVO methodologies and must be willing to change their own internal structure to facilitate interdepartmental workflows and budget integration
	Contractual organisation (the SPV model)	
	Material circularity	
Project finance	Financial evaluation of the project	Valuation standards must be developed reliably and fairly considering the additional (softer) values of PSS and CE models in the built environment, accounting for externalities which are currently and otherwise borne by society and the environment
	Transfer tax and Value Added Tax	
	Bankability: Impact on underlying cost of capital	Financing models must become broader in scope (considering technical quality, energy-efficiency, or material circularity)
	Material markets: The problem of guaranteeing residual value	
Governance and building law	Legal framework for value preservation and the argument for concentrated ownership in the real estate sector	Building law must innovate to allow for currently non-standards forms of legal and economic ownership, and of technical demarcation of responsibilities and risk
	Physical demarcation of materials, components, and systems	The concept of building ownership and utility value must be critically revised
	Technical demarcation of performance, responsibilities, and risk	Further technical comparison must be made between new PSS and CE models, and more tested forms of collaborative contracting such as DBFMO contracts (Design, Build, Finance, Manage and Operate)
	Risk distribution and bankruptcy law	A significant barrier is created by EU (and global) waste management policies, which broadly catalogue secondary materials as waste, and limit or fully restrict their transportation across international borders. This makes the economics of material recover unfeasible, particularly in countries with high labour costs were such processes fail to generate subsistence-level value

Perhaps the key challenge highlighted by this study is the broad restructuring and rethinking of the ways in which buildings are developed, managed, financed, and legally protected. The shift from valuing buildings as full functional units, to valuing them as temporary material depositories, puts into question the entire solidity of real estate investment markets. It conceptually forces together the solidity of real estate investment with the volatility of long-term material value speculation. These concepts could arguably be defined more by our culture than by economic reality, and our lack of consideration for the value of materials might significantly change once these materials become scarcer.

7 Challenges and future perspectives

On the matter of scalability of these results we consider that performance-based models can be an administrative alternative which addresses internal organisation challenges (flexibility and ease of decision-making) and external societal challenges (environmental sustainability). However, their implementation currently faces significant practical hurdles. The hurdles and conditions described are common to different types of real estate owners and project investment decisions around the world. While regional differences exist, the multi-disciplinary approach hereby described and the factors evaluated are expected to be for the most part similar, as are their consequences to CE and PSS implementation. The authors acknowledge that selecting a public entity as client/building owner resulted in specific financial and fiscal conditions which influenced the applicability of the model and the pilot project's outcome. This showcases how the administrative conditions of a building project can be more determinant than the technical specifications of the building. Because of this, the conclusions of this process highlight once again the need for a holistic planning process which integrates all relevant fields of knowledge.

The systemic innovation proposed in this paper could facilitate a shift from Total Cost of Ownership to Total Value of Service. As building technologies evolve, real estate markets fluctuate, and end-user trends change, buildings and their components must be able to adapt to this changing world technically, managerially, financially, and legally, while retaining their value. Solid real estate, inflexible to changes, could be acknowledged as a liability when compared with more flexible and 'liquid real estate' (den Heijer et al., 2016).

In the story of Theseus' ship, the vessel is repaired, and components replaced until no physical part of the original ship remains present in the current one. The thought exercise focuses on whether the ship remains the same ship, after all components have been replaced. Questions are rarely asked about the destiny of the removed components, as these seem to be hardly relevant. Theseus' ship is only one temporary application of potentially eternal materials, and therefore should not be our focus of attention. The thought experiment should focus instead on the different vessels, building structures, furniture, and infinite other applications for which the materials in Theseus' ship could be used.

FaaS	Facades-as-a-Service
PSS	Product-Service System
CE	Circular Economy
CiTG	Faculty of Civil Engineering and Geo-Sciences, Delft University of Technology
DAS	Designing an Accommodation Strategy process model
CRE	Campus Real Estate Development Team
SPV	Special Purpose Vehicle
TCO	Total Cost Ownership
TVO	Total Value Ownership
VAT	Value Added Tax
BaU	Business as Usual
TCS	Total Cost of Service
DBFMO contracts	Design, Build, Finance, Manage and Operate

8 Annex 1: Results (extended)

Table 4 presents a more extensive collection of results organised according to each. administrative process identified. Cells in the column summarizing 'Pathway to systemic innovation towards PSS' have been colour coded to represent a feasibility/readiness assessment according to the following legend:

Conditions enabling a more mainstream implementation of PSS models could be achieved through targeted action
Pathway towards PSS achievable with significant additional effort, motivation, and cost- and risk-bearing to overcome inertia
Current practices cannot support competitive PSS alternatives capable of being upscaled to the mainstream construction market.

TABLE 4 Systemic innovation pathways required for each determinant factor towards PSS for building projects.

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
Value hierarchy	The nature of the building project's commissioner's activities has a determinant influence on the prioritisation of values. For commercial property developers and owners, the building itself is the core business activity: a positive balance between hard values (operational income) and hard costs (operational expenses) is a necessary condition to render the project feasible from a business and finance perspective. In the case of corporate and public real estate the building is an operating asset used by the organisation to fulfil their core business processes or public services. This allows organisations in such segments to look beyond hard values and costs, and consider also softer factors such as strategic fit, sustainable performance, staff productivity, social goodwill, branding and sustainable perception et. A non-extensive list of factors, and their generalised prioritisation in different property segments, has been shown in Figure 3.	The question is how to evaluate the impact of these soft values reliably and fairly on a project's Total Cost (or Value) of Ownership. This will be discussed in the following section on financial parameters.
Commissioners' organisational structure	The traditional linear project flow – which consists of the development, management & exploitation, and decommissioning phases – is deeply engrained in the real estate discipline and the structure of building-commissioning organisations (Figure 4). This structure is adopted by both commercial and corporate or public real estate, even though the first will tend to have several owners throughout the building service life, while the second tend to keep ownership throughout. Development teams are in most cases different from facility management and decommissioning teams. This leads to a conflict between initial cost short-termism, long-term cost-effectiveness, and circularity requirements.	Strategic and organisational barriers were addressed in a relatively organic fashion, as evidence emerged of the need to innovate across several traditional organisational processes. Budgets allocated to different TUD departments (project development, maintenance, facility management, central university finance, and end-user faculty) were integrated into a single CiTG East façade whole life-cycle project budget. A project manager was appointed capable of bridging the multiple organisational departments.
		The project manager's experience as a technical building consultant enabled him to negotiate the FaaS service agreement with the FaaS provider, shifting the procurement process from the prescription of technical solution to an agreement based on functional requirements, including sustainability and circularity.
		A link was created between the FaaS provider, and the facility maintenance company awarded years before with a contract for the maintenance of the entire TUD campus. Part of the budget allocated to the maintenance company was transferred to the FaaS provider, since the CiTG building's East façade is no longer part of the TUD maintenance provider portfolio but instead serviced by an external party (the FaaS provider). The processing of user complaints and the adjusting of the East façade's smart technical operational algorithm is done jointly by both companies, and then discussed in open sessions with focus groups representing facility management and the faculty end-users. The smart façade technical systems algorithm controls operating conditions for the façade's external sun-shading system and night-cooling system and is therefore determinant to the correct functioning of the façade in relation to the technical service requirements established in the service agreement, such as user comfort.
Project briefing	The procurement process is not only defined by the strategic priorities / objectives, value hierarchy, and organisational structure of the project commissioner (the problem-owner), but it is bounded by the range of possible solutions the market presently offers. In the case of performance-based procurement, as with other innovations, this pull/push mechanism between demand and supply often results in stagnation and a "circle of blame" in which suppliers do not offer product-service combinations that commissioners are not asking for, while commissioners do not ask for such combinations because no suppliers are (reliably) offering them.	The FaaS pilot project showcased both sides of the innovation push/pull argument: to enter a full PSS contract, on the one hand TUD's commissioners had to integrate the scope, expertise, and budget of the project development and facility management teams, and even of the end-user faculty, in order to provide a complete list of functional requirements. On the other hand, a clear demarcation had to be found on which factors the FaaS supplier consortium could be held liable for. For example, in the case of energy consumption and user comfort, Faas supplier consortium would not bear the risk of energy price volatility, performance of the central building energy system, and extreme weather events. A full list of unbearable risks related to the functional requirement was negotiated. It must be stressed that some of the performance limitations could be attributed to the fact that only one of the building's facades had been renovated, so that guaranteeing performance over the whole building's functional requirements (e.g. energy consumption and indoor comfort) was impossible. It would be expected that such limitations would not apply in the case of a full building envelope PSS intervention.

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TABLE 4 (*Continued*) **Systemic innovation pathways required for each determinant factor towards PSS for building projects.**

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
	Gielingh and co-authors (Gielingh 2008, Gielingh et al. 2008) make a distinction between the functional requirements needed by the building owner and end user, and the technical solutions offered by suppliers to fulfil these requirements. Several authors on project commissioning theory have highlighted the drawbacks in project briefing processes being too technically prescriptive, resulting in inefficiencies such as:	
	• Suppliers and products become commoditised, as the scope provided for innovation or added value are largely restricted by the commissioning process.	
	• The focus of the transaction is on the delivery of the prescribed physical products (and the embedded material resources), rather than the ongoing and efficient fulfilment of the desired performance requirements.	
	• The resulting building is a static, depreciating object, inflexible to changes in technology, market or user demands.	
	• Service-life performance, End-of-Service scenarios, and residual value of components are not factored into the decision-making process.	
Contractual organisation (the SPV model)	Traditional project structures rely on the contracting party generally a real estate developer or operator securing financial resources to initiate, retrofit, maintain, etc. a construction project. Resources are secured usually through a property-backed mortgage, depending on the type of client, acquired through public fiscal funding (public and semi-public clients), corporate revenue, equity, and debt (corporate clients), and project financing through equity and debt (commercial clients).	In a full Product-Service System model the contracting party prefers not to have legal and economic ownership of the operating assets but would rather outsource these to the third-party service provider. The current system of building law and project financing cannot easily deal with such a proposition. An asset with a relatively long service-life, such as a façade, is not an easy object to finance for a bank or leasing company, as they would with industrial or office equipment with shorter (<10-year) service lives.
		• The financier would have to commit to a 50-to-70-year financing period (the usual service-life of a façade). Alternatively, a shorter financing period could be agreed, but re-financing risk would have to be borne by the building owner. In the absence of a refinancing option the building owner would be forced to purchase the façade, and the PSS model would become ineffective and its circularity potential lost.
		• A second option would be for the FaaS provider to arrange the financing, essentially becoming a building envelope developer. However, façade companies are usually SME's, with limited loan-bearing capacity and a corporate and financial structure meant for manufacturing and/or assembly, and not for real estate investment. During the early stages of the project, it was concluded that most façade builders (except for perhaps the largest multinational companies) would be unable to finance and keep in their balance sheet more than a handful of FaaS projects. This solution would therefore lack scalability.
		The solution found, as summarized in the Figure 5 diagram, overcomes these contractual and financial barriers by integrating bank, client, and FaaS provider with a fourth stakeholder: a Special Purpose Vehicle (SPV), created in most likelihood by a real estate investment and management fund used to dealing with long-term building projects. The SPV would act as a mediator between the collaborating partners. It would retain legal and economic ownership of the façade, arranging financing and managing the service contract with the FaaS provider in the final interest of the building owner (client). The SPV can retain a long-term planning horizon, knowing that the facade will probably remain in place for decades, but otherwise brokering a new location where it can be installed. Building owner, financier, and even FaaS provider can be replaced if the building is sold to a new owner, the first financing term concludes, or the FaaS provider faces bankruptcy or stops providing façade services for any reason.

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TABLE 4 (*Continued*) **Systemic innovation pathways required for each determinant factor towards PSS for building projects.**

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
Material circularity	The key circular value proposition in the built environment is to convert a building owner's 'liability' to manage their building materials in a circular way, into a financial incentive or an asset for the providing entities. Retaining, maximizing, and extending the value of materials indefinitely by applying re-life options with both 'retroactive' and 'proactive' circularity leads to positive long-term spill-over effects, such as stabler supply and value chains, savings in pollution taxes / fees, preventing loss of end-of-service value, etc.	In the case of the CiTG building, the existing façade included asbestos (as was usual at the time of construction), so that the deconstruction of the façade was not practically possible. A company was found with a new method for separating asbestos from steel, however their processing plant was under construction and would not be ready for another 2 years, during which time TUD would remain legally responsible for the correct management of the asbestos-containing steel frames. This was considered too high a risk by the commissioner, and the decision was made to traditionally dispose of the equipment in a way that is safe but prevents the recovery of the contaminated materials.
	With 'retroactive circularity' we can define the circular End-of-Life management of legacy equipment already installed on current buildings. The building owner must traditionally hire a demolition or deconstruction company to remove the materials before a replacing building system can be installed. Most often buildings are demolished, leading to significant 'material leakage' and loss, but in some cases, they will be deconstructed in a way that material value can be recovered.	The CiTG project's relatively small scale and tight construction schedule made it impossible to develop and integrate new technical solutions for a more circular façade system in time, however, the consortium involved in the project, together with other industry parties, continued working on these technical challenges and developed the Ciskin façade system beyond the scope of the project (Alkondor, de Groot & Visser, and Wicona 2022).
	With 'proactive circularity' we can define the development of new technologies capable of more efficiently enabling fully circular material reprocessing. It must be noted that existing technical solutions (i.e. framing systems and façade-integrated technologies) are already quite capable of allowing certain degree of updating and reprocessing, so that the field is ripe for this transition.	
Administrative process	**Project finance**	
Objectively determinant factor to the success of a FaaS procurement model	**Current situation**	**Pathway to systemic innovation towards PSS**
Financial evaluation of the project	Traditional project-financing investment evaluation, which is at the heart of a project's decision-making process, aims to limit risks by focusing on the "hardest" values and costs expected from a construction project (Figure 3). In recent years the discussion around Total Cost of Ownership (TCO) and Total Value of Ownership (TVO) has emphasised the relevance of softer values and liabilities.	In the FaaS project an intermediate TCO/TVO method was pursued, in which a hard factor evaluation would lead the decision-making, but an estimate of selected soft values would be provided as supporting input. The evaluation thus included a cash-flow and a TVO analysis, both studies we performed with planning horizons of 15 and 30 years. In the case of the 30-year study it is assumed that *the façade will have to be replaced on year 15*. This as it is unrealistic to assume that an already 60-year-old and technically inadequate façade system can remain in place for an additional 30 years, no matter how frequently it is given minimum maintenance. The results of the cumulative TVO calculations can be found in Figure 6., while the cumulative distribution over time of the TVO results have been shown in Figure 7.
		First, the results illustrate the wider reason why deep energy façade renovations are failing to reach mainstream volumes. When looking at a 10-20-year planning horizon (as most building owners do), the decision to perform minimum maintenance and defer larger decisions to a later date is supported by the financial case. In the case of commercial real estate this is exacerbated by the likelihood that the current building owner might decide to sell the property before a mayor renovation point is reached. Only when soft values and the estimated opportunity cost of suboptimal user comfort are considered, does the business case support a decision to renovate sooner rather than later.
		Second, results show that a PSS model is not necessarily more expensive than a traditional linear model from a long-term TVO perspective. While externalised financing and maintenance costs make the PSS alternative more expensive on a

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TABLE 4 (***Continued***) **Systemic innovation pathways required for each determinant factor towards PSS for building projects.**

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
		yearly basis, avoiding the need to invest capital upfront frees up building owners' resources which can be used for alternative projects with their own (potential) financial returns, while still providing the added values of a retrofitted façade.
		Thirdly, borrowing conditions resulted a difficult barrier to overcome. As a public organisation TUD has access to direct government borrowing at preferential rates, so that financing the project via a commercial third party (the SPV FaaS provider) would involve a higher Cost of Capital.
		The value of material circularity of the new façade could not be considered as part of the financial model because no bank would consider the residual value of the façade in their project financing model. This resulted in an additional increase in the FaaS model's Total Cost of Service (TCS). As a result of these two factors the TCO analysis, from the building owner's perspective, was not in favour of the FaaS model. Conditions would have been expectedly different for a commercial building owner (for whom Cost of Capital is generally higher, and more similar to what the SPV FaaS entity could apply for). Conditions could have also improved if the residual value of the façade was considered in the project's financial evaluation.
		After reviewing these results, the building owner TUD decided to undergo a deep energy renovation, but not to finance it through PSS because as a publicly university they did not expect a significant financial performance from an alternative investment, rendering one of the key values behinds a PSS model invalid.
Transfer tax and Value Added Tax	Tax policy is highly dependent on geographic region. Even within the European Union, despite general trends and shared basic concepts, each member state has different rules regarding construction projects and real estate property taxation. This is highly related to the country's building law ideology (more on this below). For this reason, the analysis below is provided for illustration purposes of the Dutch case, and as a regional example of how fiscal policy can affect the implementation of circularity-enabling PSS.	Several tax advisors provided conflicting views on how the Dutch tax authorities would react to the question of transfer tax in the PSS scenario. However, no references could be found in either literature or case law, rendering the question open until the Dutch tax authorities ruled a decision on the matter. This would only happen if a decision to procure a FaaS system was first made by TUD, and the Dutch tax authorities were asked to rule on the fiscal consequences of the decision.
	In the case of The Netherlands, a general distinction is made between:	A. In a traditional construction project a 21% VAT would be applied to the cost of materials and labour delivered by the façade supplier to the building owner. In the case of a PSS model, the 21% VAT would be deducted by the FaaS SPV (as a commercial business expense), and would therefore not be charged to the building owner up front. Instead, a 21% VAT would be charged on the monthly FaaS service fees charged by the SPV to the building owner.
	A. A building's construction (or renovation) phase, during which materials and labour are being commissioned for the project which are eligible for a Value Added Tax (VAT), which in the Netherlands is 21% (with some exceptions); and	B. According to most fiscal advisors consulted, once the first fabricated façade modules are being fixed onto the building, then the building owner will automatically become legal owner of the façade panels. If the FaaS supplier was to become legal owner after construction has started, then transfer tax must (most likely and in most cases) be paid. To avoid additional taxation and considerable costs therefore the *FaaS decision must be made before the façade construction process (on site) is initiated.* Some tax advisors suggested that transfer tax would not be applicable if the façade was transferred to the FaaS SPV before the project officially concluded and technically delivered, but this could not be verified until it was implemented (resulting in a 6% risk for TUD over the entire new façade's transactional value).
	B. A building transaction involving a finished and functional real estate object, which can be an entire building or a fractional part of it (e.g. a flat in an apartment block). In this second case, in the Netherlands, a transfer tax of 2% for residential buildings and 6% for non-residential buildings is applied[2].	The risk of transfer tax being due applied significant pressure that the SPV's corporate structure, financing application, and contractual definition were finalised before the CiTG's East façade was technically delivered. This process was impossible within the remaining timeframe, exacerbated by time constraints established by the CiTG façade's technical replacement planning, and its strict delivery deadline before the end of Q4.2020. This resulted in an unknown and unexpected risk for TUD as commissioner and was a crucial point in the final decision not to implement a full PSS model for the CiTG façade renovation.

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TABLE 4 (*Continued*) **Systemic innovation pathways required for each determinant factor towards PSS for building projects.**

<table>
<tr><th>Administrative process</th><th colspan="3">Management</th></tr>
<tr><th>Objectively determinant factor to the success of a FaaS procurement model</th><th>Current situation</th><th colspan="2">Pathway to systemic innovation towards PSS</th></tr>
<tr><td rowspan="7">Bankability: Impact on underlying cost of capital</td><td rowspan="2">The valuation of a building is of primary importance to the building owner, regardless of whether the owner is a commercial, corporate, or (semi)public party, because it will determine its effectiveness as collateral in a loan application. In the present economic system, the value as collateral of real estate is among the most secure guarantees a lender can have, and thus contributes to lower interest rates than other types of collateral securities. If the loan is not serviced then the building can be foreclosed and, except during downturns in real estate cycles, the principal on the loan can be for the most part recovered by the lender.</td><td colspan="2">The building façade is usually around 20% of the initial cost of a building project, while a building- for most purposes- is not usable if it doesn't have a façade. To what extent would externalising the façade legal and/or economic ownership affect the value of the building as collateral was the subject of significant academic and professional debate in the FaaS project.</td></tr>
<tr><td colspan="2">In the case of the CiTG façade, no valuator could commit to a final response, but rather three arguments emerged which are summarised below. Most likely, as in the case of taxation, whether the building owner kept (or could easily contractually recover) legal and/or economic ownership of the façade would also determine how the FaaS construction would be treated in a valuation assessment.</td></tr>
<tr><td rowspan="4">Organisations of all types use the value of their owned buildings as collateral to secure low-interest loans. A broad difference exists, however, in the loan conditions (e.g. loan terms and interest rates) accessible to different types of organisations. Commercial organisations have a higher risk profile since the building itself is at the core of the clients' business model and its source of revenue. Loss of income related to the building's operation would lead to incapacity to service the loan. As a result of this, loans tend to be for a shorter period and involve a higher interest rate. Corporate and (semi)public clients, meanwhile, have additional sources of revenue, since the building is only an operating asset facilitating their core activities, and are therefore more secured borrowers. Loan terms will be longer and interest rates lower, in particular for (semi)public organisations able to borrow directly from the government at national central bank rates.</td><td>Arguments</td><td>Description</td></tr>
<tr><td>The higher project cost of a FaaS alternative would result in a lower debt-bearing capacity of the building owner.</td><td>As the monthly costs of a PSS are higher than in a purchased façade, while the gains from an alternative investments are most likely not considered in the building-specific financial evaluation linked to the project's bankability.</td></tr>
<tr><td>This higher project costs could be positively counter-balanced, in a valuation, by the gained benefits to the building and its occupiers.</td><td>Improved quality and performance of the building, energy savings, and user comfort. All these factors would contribute to a higher transactional value of the building and therefore would render it a more valuable guarantee as collateral.</td></tr>
<tr><td>The legal model used to commission the FaaS would have an impact on the (split) ownership of the building, and therefore the building's value as collateral.</td><td>Due to the uncertain nature of the legal model in the case of a dispute, as will be described below, and the lack of precedents in either legal literature or case law, a certain and final answer could not be provided.</td></tr>
<tr><td>As part of their due-process obligations, valuators are responsible and liable for following existing valuation standards and securing to the financial institution aiming to guarantee the loan that the collateral value of the building has been correctly assessed. As a result of this, valuation standards and practices are generally risk adverse, and slow to change.</td><td colspan="2">The risk of lost value as collateral, while not fully confirmed, was deemed to be manageable, even in the case that the SPV model removed legal ownership of the façade entirely from the building owner. The loss of physical material value of functional unity would be offset by the higher building utility and transactional value. Also, the long term of the eventual FaaS contract (15-30 years), would mean that even in the case that the building was sold the FaaS contract (and the underlying façade) would be transferred with it and the building's functional unity would be preserved.</td></tr>
<tr><td>Material markets: The problem of guaranteeing residual value</td><td>The fundamental philosophy in states with a European systemic heritage, which underlies building law since its roots in Roman jurisprudence, is that buildings are financed based on their value as a complete functional unit. As such, they can be used as collateral to guarantee a loan, in other words mortgage-based financing. This loan, however, will always have a shorter term than the expected service life of the building. The lender does not want to assume any risk over the maintenance of the building by its owner/manager, or over the building's End-of-Life (EoL) scenarios. The loan must thus be fully repaid before major renovation reinvestments or EoL processes are to be reasonably expected which would lead to a change in the utility value of the building.</td><td colspan="2">It would not be an exaggeration to define the treatment of buildings as material banks as a fundamental paradigm shift in the context of real estate financing, and thus a determinant factor on the evolution of the built environment. To account for the residual value of materials, the financier would have to essentially invest in the future value of secondary material markets. This last sentence summarises the extent of the risk perceived by a potential lender:</td></tr>
</table>

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TABLE 4 (*Continued*) Systemic innovation pathways required for each determinant factor towards PSS for building projects.

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
	In the current construction market, the residual value of materials found in buildings is therefore of no positive consequence to financial or real estate markets, which means that it does not contribute to the value of the building as collateral when securing a loan. In most cases, it does not even provide the building owner with an expected recoverable income at the time of decommissioning. In fact, most frequently, building owners will need to pay for the demolition and removal of used or obsolete components, so that the removal costs remain a liability which should be considered in the balance-sheet of the building owner.	• *Future value:* Which in the case of buildings and building components must be projected several decades into the future. • *Secondary materials:* Meaning that long-term forecasts and assumptions must be made regarding recycling and reprocessing technologies, social and cultural views on reuse of components and materials, evolving building technologies and practices, and several other trends and factors. • *Material markets:* Which are generally volatile, but which have seen particularly unprecedented fluctuations as a result of recent crises such as the ongoing COVID-19 pandemic and the consequences of geopolitical conflicts and tension (World Economic Forum 2022). Also, several studies have shown that long-term material value trends have changed, and in fact reversed, since around the year 2000, so that no long-term historical data can be counted upon during the financial evaluation (Ellen MacArthur Foundation 2013). This is probably the most essential and complex question in the transition towards circularity in the built environment: How to combine low-risk investment in real estate with high-risk investment in building materials? Unfortunately, the answer to this question is far beyond the scope of this paper. While several discussions were held on the matter with diverse financiers during the FaaS project, and several positive arguments were presented, no final consensus could be reached. None of the financiers consulted would consider a loan longer than a traditional mortgage, nor would they consider a positive balance in the project's cashflow as a result of the potentially recoverable value of (potentially more circular) components and materials.
Administrative process	Governance and building law	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
Legal framework for value preservation and the argument for concentrated ownership in the real estate sector	The "rule of accession" provides ownership of all immovable structures and fixtures to the owner of the land or structure on to which they are fixed. This is the case not only in the Dutch context but throughout a large part of the world, across countries whose governance has been influenced by Western thought, and whose legal codes have been fundamentally inspired by the Roman legal system (Van der Walt and Sono 2016). As stated by (Ploeger et al. 2018): "the purpose of property law is to offer legal security and to minimise transaction costs and to maximise and preserve real estate values in society".	In the context of applying PSS models to the construction sector, as has been discussed by (Chao-Duivis 2018) and (Ploeger et al. 2018), the argument for split ownership of building layers and systems clashes with the legal framework under which the real estate sector has been traditionally regulated.
	The argument for concentrated ownership is therefore based on the concept that the whole is more valuable than the sum of its parts, and that a real estate object is more likely to lose value or face transactional disputes if ownership of its essential components is divided among several legal entities with diverse or even conflicting economic interests.	It is however desirable, as the retention of legal ownership - by the service provider - of any tangible material products needed to deliver an intangible performance service will provide the additional legal and economic incentives to effectively reprocess materials and components through reuse, repair, remanufacturing, and/or recycling activities (Baines and Lightfoot 2013, Stahel 2016).
	With the rising complexity of buildings and building systems, the essential nature of any individual component can be disputed. The law has therefore focused on a broad definition of essential components as "fixtures", or any component that is physically attached to the building and whose removal would result in significant destruction or loss of key functions.	In the FaaS project, the challenge of legal ownership was considered addressed with sufficient certainty and risk-avoidance when the model was proposed in which the FaaS provider would rent the contact points on which the façade would be connected to the structure, from the building owner. A right of leasehold could be established by which the building owner would lease from the FaaS provider the façade, while the FaaS provider would install the façade on the contact points that it in turn rented under a long-term contract, thus avoiding the automatic transfer of legal ownership under the rule of accession. While not certain until its first potential litigation (in the future), the model was considered sufficient by legal academic and practice experts.

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TABLE 4 (*Continued*) Systemic innovation pathways required for each determinant factor towards PSS for building projects.

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
		Contractual allocation of technical responsibility and risk was the focus of another research group. This resulted in the development of a detailed technical service agreement in which were established the scope of activities which the FaaS provider had to perform, and the contractual reaction time within which these activities must be performed. A distinction was also made between expected maintenance against natural wear and tear, and special maintenance resulting from incorrect engineering, manufacturing, or user behaviour. Such special maintenance, determined on a case-by-case basis, would still have to be addressed within the contractual reaction time, but it might not be covered by traditional product guarantees, nor by the FaaS service agreement.
Physical demarcation of materials, components, and systems	Van der Plank and de Jong (2019) recognise a distinction between tenancy (apartment) law and lease law.	Lease law is most frequently applied to horizontal surfaces, for example leasing a plot of land for a defined period to erect a temporary structure on it. In principle, however, the cited authors find no fundamental reason or precedent preventing such a construct from being applied to vertical surfaces as in the case of a façade, which has been the case for the FaaS project.
	The former implies legal ownership of a functionally independent unit (such as an apartment within a residential block), even when the provision of certain key functions (e.g. circulation areas and central heating) are collectively owned by the community of owners.	The challenge of physical demarcation was illustrated by the case of a state-of-the-art façade system with high service integration: The curtain wall – which consists of framing, glazing, panelling, and other potentially integrated decentralised components such as solar shading, actuators, or BiPV units – could be clearly defined as a self-contained physical object. The interface between the curtain wall and other building elements (e.g. structural brackets or supporting timber framing), could be included or excluded from the leased system, but will most likely also be leased together with the curtain wall. Probably the biggest challenge to this physical demarcation lies in cabling (e.g. electricity and ICT) and piping (e.g. heating and ventilation), which could in many cases be largely interconnected with the centralized building services infrastructure. As the PSS in FaaS was only partially implemented (as a service contract without lease), this aspect was left unresolved.
	Lease law, meanwhile, deals with economic ownership (i.e. right of use) of a technically definable but not necessarily functionally independent object. Right of lease is in principle unrelated to the spatial and functional integrity and autonomy of the leased unit. As long as a clear physical distinction can be made between those buildings, systems, or components which are owned by the landowner, and those which are being leased from a third party, a right of leasehold should be definable. The complexity of such a definition could become a challenge in the case of building systems which are not spatially contained but are instead widely integrated throughout the building (i.e. centralised builder service installations).	
Technical demarcation of performance, responsibilities, and risk	Technical performance in traditional product-based offerings is largely constrained to limited warranties against certain types of defects in manufacturing or installation. These warranties tend to be limited to several years, typically below the expected service-life of the product, thus essentially transferring a large part of the component's operational failure risk to the client.	As we approach "result oriented" PSS offerings (Tukker 2004), the definition of technical performance expands to include not only the technical integrity and direct output of these components, but the final operational outcome which the system should deliver to the client's processes. In the case of a "functional result"-based FaaS contract (the highest level in Tukker's categorisation) the expected contribution of the façade to the client's processes would be the delivery of a specified energy performance (or savings against an initial benchmark), the delivery of a determined indoor comfort, and ensuring a certain degree of circularity. In such a scenario it is easy to envision several contractual arguments emerging:
		- Interaction between the façade system and centralized building services: in most buildings, the delivery of indoor comfort is the result of interaction between the building envelope and integrated decentralized systems and centralized building services (such as ventilation, lighting, heating and cooling). This division could lead to an uncertain demarcation of performance responsibility between contractors, or between components owned directly by the owner and those being leased or hired under a performance contract.

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TABLE 4 (*Continued*) Systemic innovation pathways required for each determinant factor towards PSS for building projects.

Administrative process	Management	
Objectively determinant factor to the success of a FaaS procurement model	Current situation	Pathway to systemic innovation towards PSS
		- User behaviour and user preference: documentation of the role of user behaviour on actual energy savings (i.e., after a deep building energy renovation), show the potential disruptive effect of negative user behaviour on final energy performance. This could lead to conflict between provider and client regarding the reason for not achieving the expected energy performance.
		As mentioned in Task 3, these aspects resulted in partial implementation of PSS for the façade of the CiTG building. In theory, with full envelope PSS, these aspects could be overcome.
Risk distribution and bankruptcy law	Entering any legal relation as established by a contract presents opportunities and risks which must be carefully assessed by both parties. The case of a contractual relation expected to last decades means, for example, that the individuals representing the organisations which have entered the contractual relation will no longer be part of these organisations by the end of the contract. Such contract lengths are not unprecedented but are most often found in relatively simple agreements involving governmental and non-governmental organisations, such as for example a 100-year land lease awarded to a building owner who does not own the land on which the building stands.	In the case of a FaaS contract, parties will seek securities to protect them in case any of the other stakeholders wish to voluntarily exit the agreement or are forced to exit by unforeseeable events such as bankruptcy. Such securities don't exist in the current construction and real estate market and had to be developed during the CiTG project. Referring once again to the SPV model previously described some of these guarantees are illustrated in **Figure 8**, and described below.
		• A façade reuse/remanufacturing broker can facilitate the transaction between one FaaS contract and the next, so that a FaaS system removed from a building can be adjusted to fit onto another one. Such parties are starting to emerge in the Dutch context. In fact, a party was found who was willing to purchase a future buy-option on the FaaS, so that it would have the right to purchase the façade at a given time in the future for a certain price. This option was not attractive in the CiTG case because TUD would in most likelihood want to continue contacting the façade for a longer period. Also, a buy-option is not an obligation for the buyer to purchase, while it is an obligation for the seller to sell, so the concept was considered too risky.
		• Since the loan for financing the project would be granted to the FaaS provider (consortium), it would not be guaranteed by the client's building. Meanwhile, as described above, the value of the façade is uncertain. In order to secure servicing of the loan several (combinable) options were explored: A financial insurance on the loan servicing, granted to the FaaS provider, but eventually paid for by the building owner as part of his FaaS fees; a buy-out option (or obligation) in which the building owner would purchase the façade from the FaaS provider (and thus pay the lender) in the event of the FaaS privider's default; and a FaaS take-over option in which the defaulting FaaS provider could be replaced by a new party, who would essentially purchase the FaaS SPV and its assets from the original consortium.
		• In terms of technical guarantees that the FaaS system would continue to be serviced, even in the event of the Façade Builder's bankruptcy, the Dutch Metal Façade Branch Organisation would commit to finding a new party willing to take over the contract with the SPV. The new party would then continue to perform technical maintenance on, as well as end-of-service processing of, the FaaS system.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

JA-A is first author of this paper, and has been responsible for its conceptualisation, structure, and research coordination. AD and MA have contributed to the research methodology and scientific validation within the broader real estate management field. LVd'A and TK have contributed with specific knowledge in targeted sections of the study.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abraham, D. S. (2015). *The elements of power: Gadgets, guns, and the struggle for a sustainable future in the rare metal age*. Yale University Press.

Alkondor, de Groot & Visser, and Wicona (2022). *Ciskin: Circular facade company*. Available at: https://circularfacadecompany.com/ (Retrieved October 29, 2022).

Artola, I., Rademaekers, K., Williams, R., and Yearwood, J. (2016). *Boosting building renovation: What potential and value for Europe*. Brussels: Policy Department A: Economic and Scientific Policy, European Parliament.

Azcarate-Aguerre, J. F., Conci, M., Zils, M., Hopkinson, P., and Klein, T. (2022). Building energy retrofit-as-a-service: A total value of ownership assessment methodology to support whole life-cycle building circularity and decarbonisation. *Constr. Manag. Econ.* 40, 676–689. doi:10.1080/01446193.2022.2094434

Azcarate-Aguerre, J. F., Klein, T., and den Heijer, A. C. (2020a). *Façade leasing demonstrator project: Final business delivery report*. Delft: Delft University of Technology.

Azcarate-Aguerre, J. F., Klein, T., and den Heijer, A. C. (2020b). *Façade leasing demonstrator project: Final dissemination activities report*. Delft: Delft University of Technology.

Azcarate-Aguerre, J. F., Klein, T., and den Heijer, A. C. (2020c). *Façade leasing demonstrator project: Final technical delivery report*. Delft: Delft University of Technology.

Azcarate-Aguerre, J. F., Klein, T., Den Heijer, A. C., Vrijhoef, R., Ploeger, H. D., and Prins, M. D. I. (2018). Façade leasing: Drivers and barriers to the delivery of integrated facades-as-a-service. *Real Estate Res. Q.* 17 (3).

Azcarate-Aguerre, J. F., Klein, T., Konstantinou, T., and Veerman, M. (2022). Facades-as-a-Service: The role of technology in the circular servitisation of the building envelope. *Appl. Sci.* 12 (3), 1267. doi:10.3390/app12031267

Baines, T., and Lightfoot, H. (2013). *Made to Serve: How manufacturers can compete through servitization and product service systems*. John Wiley & Sons.

Behrens, A., Giljum, S., Kovanda, J., and Niza, S. (2007). The material basis of the global economy: Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. *Ecol. Econ.* 64 (2), 444–453. doi:10.1016/j.ecolecon.2007.02.034

BIO Intelligence Service (2013). *Sectoral resource maps, prepared in response to an information hub request*. Paris, FR: European Commission, DG Environment.

BPIE (2011). *Europe's buildings under the microscope. Brussels, Belgium, building performance insitute europe*.

Camilleri, M. A. (2019). The circular economy's closed loop and product service systems for sustainable development: A review and appraisal. *Sustain. Dev.* 27 (3), 530–536. doi:10.1002/sd.1909

Chao-Duivis, M. A. B. (2018). *Privaatrechtelijke aspecten van de circulaire economie in het bijzonder circulair bouwen (Deel III). Het aanbestedingsrecht*. Instituut Bouwrecht: Tijdschrift voor Bouwrecht.

De Jonge, H., Arkesteijn, M. H., Den Heijer, A. C., Vande Putte, H. J. M., De Vries, J. C., and Van der Zwart, J. (2009). Designing an accommodation strategy (DAS frame). Delft: TU Delft. Department Real Estate and Housing, Faculty of Architecture.

den Heijer, A. C. (2011). *Managing the University Campus: Information to support real estate decisions*. Delft: Eburon Academic Publishers.

den Heijer, A. C., Arkesteijn, M. H., de Jong, P., and de Bruyne, E. (2016). Campus NL: Investeren in de toekomst.

den Heijer, A. C. (2013). Assessing facade value-how clients make business cases in changing real estate markets. *J. Facade Des. Eng.* 1 (1-2), 3–16. doi:10.3233/fde-130004

Ellen MacArthur Foundation (2013). Towards the circular economy. *J. Industrial Ecol.*, 23–44.

European Commission (2016). *Proposal for a directive of the European parliament and ofthe Council amending directive 2010/31/EU on the energy performance of buildings,impact assessment, commission staff working document*.

Fischer, S., Steger, S., Jordan, N., O'Brien, M., and Schepelmann, P. (2012). *Leasing society: Study*.

Fox-Penner, P. S. (2014). *Smart power: Climate change, the smart grid, and the future of electric utilities*. Washington: Island Press.

Gielingh, W. (2008). A theory for the modelling of complex and dynamic systems. *J. IT Constr. (ITcon)* 13, 421–475.

Gielingh, W., de Ridder, H., Jonkers, L., and Vedder, H. (2008). "Business innovation in construction through value oriented product/service offerings for living buildings," in *1st international conference on industrialised, integrated, intelligent construction (I3CON)* Citeseer.

Krausmann, F., Lauk, C., Haas, W., and Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Glob. Environ. Change* 52, 131–140. doi:10.1016/j.gloenvcha.2018.07.003

Magrini, A., Lentini, G., Cuman, S., Bodrato, A., and Marenco, L. (2020). From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge-The most recent European trends with some notes on the energy analysis of a forerunner PEB example. *Dev. Built Environ.* 3, 100019. doi:10.1016/j.dibe.2020.100019

Ploeger, H. D., Prins, M., Straub, A., and Van den Brink, R. (2018). Circular economy and real estate: The legal (im)possibilities of operational lease. *Facilities* 0 (0).

Stahel, W. R. (2016). The circular economy. *Nat. News* 531 (7595), 435–438. doi:10.1038/531435a

Stahel, W. (2010). *The performance economy*. Springer.

The Economist Intelligence Unit (2013). *Investing in energy efficiency in europe's buildings: A view from construction and real estate sectors, committed by GPBN*. London, UK: BPIE, WBCSD.

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Bus. strategy Environ.* 13 (4), 246–260. doi:10.1002/bse.414

Tukker, A., and Tischner, U. (2006). Product-services as a research field: Past, present and future. Reflections from a decade of research. *J. Clean. Prod.* 14 (17), 1552–1556. doi:10.1016/j.jclepro.2006.01.022

van der Plank, P. J., and de Jong, D. (2019). Instrumenteel gebruik van het recht van erfpacht in het kader van circulair bouwen. *Weekbl. Privaatr. Notar. Regist. SDU*, 64–70.

Van der Walt, A., and Sono, N. (2016). The law regarding inaedificatio: A constitutional analysis. *THRHR* 79, 195.

Van der Zwart, J., Arkesteijn, M. H., and Van der Voordt, D. J. M. (2009). "Ways to study corporate real estate management in healthcare: An analytical framework," in *Proceedings HaCIRIC 2009, 2nd annual conference of the health and care infrastructure*.

Vergara d'Alençon, L. M., Arkesteijn, M. H., Azcarate-Aguerre, J. F., den Heijer, A. C., and Klein, T. (2019). *Circular business models: Building a database of case studie*. Delft, NL: Delft University of Technology.

Vezzoli, C., Kohtala, C., Srinivasan, A., Xin, L., Fusakul, M., Sateesh, D., et al. (2017). *Product-service system design for sustainability*. New York, NY: Routledge.

Widmer, T., Tjahjono, B., and Bourlakis, M. (2018). *Defining value creation in the context of circular PSS*. Procedia CIRP, Elsevier B.V.

World Economic Forum (2022). *How to reinvent supply chains in a new global economic order*.