

PRODUCT-SERVICE-SYSTEM (PSS) IN TAIWAN'S PUBLIC HOUSING PROJECTS- DEVELOPMENT, BARRIERS, AND FACILITATORS

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ABSTRACT

Background and aim. Since 2018, various public sectors in Taiwan have started introducing the “circular economy” concept and implementing new business models, such as Product-Service-System (PSS), into their new housing projects. After several years of construction and operation, the feasibility of this new model has not yet been explored. This study aims to disclose whether the implemented PSS in these new public housing projects has reached its original goals of enhancing building circularity (e.g., extending products’ lifespan, remanufacturing products) and long-term profit.

Methods and Data. In this preliminary study, data related to the original plans and actual performances of the implemented PSS is collected via interviews with project owners of these pilot public housing projects. Discussions on the potential reasons behind its success/ failure and suggestions to other project owners who plan to adopt a similar model are also made in the interviews.

Findings. The study identified several barriers to the success of the PSS model in Taiwan’s public housing projects, including contract ambiguities, inappropriate bidding methods, and miscoordination during construction and installation. In the meantime, potential facilitators are also identified, including a more mature PSS ecosystem, supportive governance systems, coordinated management schemes, and increased resident sustainability awareness.

Theoretical / Practical / Societal implications. PSS for building operations in Taiwan’s public housing projects is a pioneering experiment. Their experiences provide valuable insights for other Taiwanese projects and guide countries that newly adopt PSS in the building industry, helping them transition towards a more sustainable, circular built environment.

KEYWORDS: Circular Business Model, Product-Service-System (PSS), Product-as-a-Service (PaaS), Public Housing

1 INTRODUCTION

Despite recent advances in building energy efficiency and urban liveability, the built environment remains largely based on a linear model, where materials are extracted, used, and discarded as waste (Arup, 2022). This model generates substantial structural waste and positions the built environment as one of the largest consumers of raw materials, as well as a significant source of waste and carbon emissions. For instance, buildings account for around 50% of resource extraction and consumption in the EU, 30% of its annual waste generation, 40% of energy consumption, and 36% of energy-related greenhouse gas emissions (EU, 2022). Moreover, urbanization will rise from 55% to over 66% of the global population by 2050, doubling the size of the built environment and straining urban systems like water, energy, and waste networks (UN, 2018).

To address the environmental problems stated above, governments, academia, and practitioners worldwide aim to transform the building and construction industries from their linear model into a circular one (Guerra et al., 2021). Many tried to identify suitable strategies and approaches for their building projects (Tseng et al., 2021). However, implementing a circular economy in the building industry is more challenging than others because of the customized nature of a building and the complex compositions and distinct lifespans of different systems within (Pomponi & Moncaster, 2017). Another key research question to be answered is how new business models can foster a circular economy in the building industry (Munaro et al., 2021). Among them, Product-Service-System (PSS) is renowned as one of the most powerful tools for transitioning society to a resource-efficient, circular economy (Tukker, 2015). A more general definition of PSS is “a mix of tangible products and intangible services designed and combined

so that they are jointly capable of fulfilling final customer needs” (Tukker and Tischner, 2006).

Following the international trend, Taiwan’s central and local governments started embracing the concepts of circular economy, nurturing several public housings as pilot projects since 2018 (Chang & Hsieh, 2019). Besides adopting new design approaches, building materials, and construction methods, new business models such as PSS are also introduced in these projects. The PSS model applies a vast range of building services, including air-conditioning, lighting, appliances, sanitary fixtures, furniture, and elevators. After operating for several years, how this newly implemented model performs requires further investigation. Meanwhile, existing research on the integration of PSS in circular housing remains fragmented, with a focus on technical challenges and business models, yet lacking empirical studies tailored to specific housing contexts (Ghafoor et al., 2023, 2024). Moreover, there is insufficient understanding of the role of project owners in the adoption and implementation of PSS, highlighting the need for more comprehensive, context-specific insights.

This study aims to disclose whether the implemented PSS in these public housing projects has reached its original goals of enhancing building circularity (e.g., extending products’ lifespan, reusing or remanufacturing products) and long-term profit. In this preliminary study, data related to the original plans and actual performances of these PSS is collected via interviews with project owners of these pilot projects. Discussion on the potential reasons behind its success/ failure and suggestions to other project owners who plan to adopt a similar model are also made in the interviews.

2 LITERATURE REVIEW

Housings account for a majority of global building stocks, pushing demand for natural resources, leading to severe environmental impacts (Zhang et al., 2024). Its shift to a Circular Economy (CE) offers a solution, yet most efforts focus on technical challenges related to building lifespan and complexity, neglecting housing-specific issues. Research highlights the need for new business models to facilitate circularity, with the Product-Service System (PSS) emerging as a promising approach. However, its role in circular housing remains poorly understood, with fragmented literature across multiple fields.

Ghafoor et al. (2023) employ an integrative review to explore the relationship between PSS and CE in housing, proposing a conceptual framework that positions PSS as a life cycle strategy to enhance efficiency, longevity, and sufficiency in energy, material, and space use in housing. It also examines the economic and social value of PSS, along with its potential impact on current housing industry structures and the transition towards PSS-based practices. Finally, the paper identifies gaps in existing research and outlines directions for future study, practice, and policy development.

Their proposed framework provides a good knowledge base to identify what types of PSS are adopted in our study cases and what benefits should be examined. Moreover, one of the key directions they have proposed for future study is the systemic analyses mapping the transition from traditional models to PSS, particularly regarding its influence on roles, relationship dynamics, and power associations. For instance, inspecting the impact of regulatory, financing, and contractual mechanisms is suggested to evaluate their attractiveness and identify potential diffusion ways (Britton et al., 2021). Empirical studies tailored to specific housing contexts would help develop contextualized insights, moving beyond generic recommendations to account for the unique characteristics of various housing categories. Our case study of Taiwan’s public housing adopting PSS can fill this research gap by delivering valuable, context-specific insights into these mechanisms’ practical application and outcomes in a unique housing setting.

To bridge the gap mentioned above, Ghafoor et al. (2024) conducted a multiple-case analysis study, examining five leading practitioners through interviews and document analysis. The research resulted in an empirically grounded framework of 14 guiding principles, offering actionable insights for PSS in circular housing. These principles adopt key business model aspects, including value proposition, value creation & delivery, and value capture. The study also highlights the pivotal role of intermediary-led collaborative value networks in hastening PSS and CE adoption in housing.

While Ghafoor et al. (2024) developed their study based on interviews with practitioners from service-providing companies involved in PSS, our research expands the scope by offering insights directly from project owners. This view is crucial as project owners play a significant role in the decision-making related to adopting and implementing PSS in housing projects. By engaging with project owners, our study provides knowledge on the challenges, priorities, and opportunities they face when integrating circular economy principles. This approach bridges the gap between the service providers and those responsible for executing these projects, ensuring a more comprehensive framework for PSS in the housing sector.

Meanwhile, Azcarate-Aguerre et al. (2022) provided a comprehensive exploration of PSS in the building sector, focusing on facades-as-a-service (FaaS) through multi-stakeholder collaboration and pilot projects in the Netherlands. Their work highlights the role of advanced technical integration, asset tracking, and performance-based contracts in enabling circularity. However, such studies predominantly focus on technologically mature, supplier-driven models. In contrast, this study addresses the adoption of PSS in Taiwan’s public housing sector, where governance constraints, procurement rigidity, and resident behaviors emerge as key barriers.

3 METHOD

In this preliminary study, data related to the original plans and actual performances of the implemented PSS are collected via interviews with project owners of these pilot public housing projects. Discussions on the potential reasons behind its success/ failure and suggestions to other project owners who plan to adopt a similar model are also made in the interviews.

3.1 STUDY CASE AND INTERVIEWEE SELECTION

Two public housing projects in Taiwan provide the most diverse services via the PSS model, i.e., Taisugar Circular Village (TCV) in Tainan and Bade No.3 Social Housing (B3SH) in Taoyuan. More information about these cases is shown in Tables 1 & 2. More information about the two interviewees is shown in Table 3, who represent project owners' viewpoints, providing valuable data and insights. It is important to note that the sample size is limited to two projects and two interviewees, which may not fully represent the broader spectrum of experiences across all public housing projects in Taiwan. The influence of this limitation on the results should be considered when interpreting the study's conclusions.

Table 1: Basic information on the selected study cases



info	TCV	B3SH
picture		
location	Tainan	Taoyuan
built year	2021	2023
housing unit	351	524
PSS type	use-oriented (Tukker, 2004)	
PSS service	9 items	3 items
bidding type	the lowest bid	the most advantageous

Table 2: Basic information of the PSS in the selected study cases- their service provider type and service length

service	TCV	B3SH
air-conditioning	PW-10 years	PM-10 years
lighting	PW-10 years	
appliance	PW-10 years	
sanitary fixture	PW-10 years	
water heater		PM-12 years
furniture	PW-6 years	PM-12 years
mattress	PW-6 years	
smart door lock	PM-10 years	
waste disposer	PM-10 years	
elevator	PM-20 years	

*PM stands for product manufacturers, while PW stands for product wholesalers.

Table 3: Basic information of the interviewees

info	TCV	B3SH
position title	engineer in the Office of Land Development	chief engineer in the Office of Housing Development
role in project	composing PSS contracts, bidding, supervising service providers	
experience	10 years	30 years

3.2 INTERVIEW QUESTION DESIGN

Interviews were conducted by following the four main questions as shown below:

- (1) What are the original motivations/ expectations for adopting the PSS model in your project?
- (2) What are the actual performances/ outcomes of the adopted PSS in your project?
 - Was the product lifespan extended after planned maintenance and repair? Was the product reused/ remanufactured after its end-of-life?
 - Did your service provider profit? Did you save money by reducing cost of maintenance/ repair?
- (3) What are the reasons behind the success/ failure of the adopted PSS in your project?
- (4) What are your recommendations to other project owners who want to adopt the PSS model?

4 RESULT

4.1 ORIGINAL MOTIVATIONS/ EXPECTATIONS

The TCV interviewee responded that the influence of national policy was one of the key drives for them to adopt a new circular business model (i.e., PSS). Founded in 1946, Taiwan Sugar Corporation (TSC) is a state-run enterprise in Taiwan. It has gradually transformed from the "Sugar Based Production and Sales Business" into a diversified business entity that covers the agricultural, industrial, and commercial industries. Following the "Five Plus Two Industry Innovation Plan" released by the central government in 2018, TSC has incorporated the circular economy concept for innovative items such as new agriculture, pig farming modernization, and resource recycling (biogas energy and biomass material). TSC also invested in proprietary housing construction since 1986. TCV is the pilot project demonstrating their determination to incorporate circular economy principles into their land development to achieve a sustainable living environment.

In addition, the TCV interviewee answered that reducing future maintenance costs is the key expected benefit of the PSS model in their pilot project. Housing construction and rental are two of TSC's main businesses in the office of land development. Responding to the rising need for more social housing by the central government, TSC will soon construct and operate more public housing. Finding a

cost-saving, robust, and sustainable model is critical to the Office of Land Development.

As for B3SH, the interviewee responded that pressure from their competitors was one of the key drives for them to adopt the PSS model in their public housing projects. Since 2014, the Taipei City Government has started constructing many public housings to fulfill its new mayor's political promise (Chen & Rietdijk, 2025). Inspired by TCV, it also aimed to incorporate circular economy principles in its new public housing projects, including the PSS model (Tseng et al., 2021). Meanwhile, as the fastest-growing city in Taiwan, the Taoyuan City Government also urged the construction of many public housings for their citizens. Inspired by TCV and the Taipei City Government, it started adopting the PSS model in its public housing projects in 2022 to prove itself to be an innovative and green government.

In addition, the B3SH interviewee answered that relieving its financial pressure is the key expected benefit of the PSS model in their pilot project. As mentioned above, city governments in Taiwan started constructing many public housings. Nevertheless, this has become a giant financial burden to them. The PSS model enables them to split the cost of building services into numerous months and years instead of paying the full purchase fee in the construction phase at once.

4.2 ACTUAL PERFORMANCES/ OUTCOMES

4.2.1 Regarding Circularity

Regarding whether the implemented PSS enhances the building circularity (e.g., extending products' lifespan, reusing or remanufacturing products), responses from the two cases vary. The TCV interviewee said their service providers often refuse to repair the provided products, blaming that they were damaged during the construction/installation, or report that the products were too damaged to repair, charging extra for replacement. The interviewee thinks this might be related to their bidding method being the lowest bid. Many of their service providers may have cut costs to win the bid, be inexperienced in PSS, regard PSS as another payment method, and not recognize the benefits that the circular economy can bring.

On the other hand, the B3SH interviewee said that their service providers maintain and repair their products well based on their contracts. This might be related to the fact that all their service providers are product manufacturers capable of gathering and storing sufficient components of their products for repair. Nevertheless, finding enough rooms for such storage becomes a new challenge for them.

4.2.2 Regarding Profit

According to the TCV interviewee, their service providers profit well since they barely fulfill their responsibility of maintaining and repairing the products they provide based on their contracts. In contrast, the TSC's management

team at TCV had to maintain and repair those products, adding extra labor and financial burden to themselves.

On the other hand, according to the B3SH interviewee, their product providers have profited limitedly since many residents in public housings use their products wrongly. Moreover, the air-conditioning provider mainly produces their product overseas, and their profit has shrunk largely because of the large difference in exchange rates. They have been reluctant to extend this PSS model to more social housing projects.

4.3 ENCOUNTERED BARRIERS

4.3.1 Regarding Planning

According to its interviewee, one of the key barriers that TCV encountered was the ambiguity in their PSS contract. For instance, whether maintaining the air-conditioners includes cleaning their filters was poorly defined. The contracts did not include what measures could be taken to resolve the different views on the fixability of products and accountability of damages.

The TCV interviewee shared that this barrier mainly results from their lack of experience and knowledge of PSS. As mentioned above, TCV was the first pilot project in Taiwan to implement PSS for various building services. Very limited information was available for the project owner team to compose a well-defined contract. Moreover, the interviewee added that PSS for building services is a new business model for the building industry in Taiwan. Limited companies knew about it and were willing to adopt it when their project started. Hence, they were concerned that a well-defined contract might reduce the number of companies who want to join their bidding.

4.3.2 Regarding Bidding

Interviewees say unsuitable bidding methods are a key barrier to the PSS model's success. As shown in Table 1, TCV and B3SH have taken different bidding means: the lowest bid vs. the most advantageous. As mentioned earlier, the TCV interviewee thinks that the lowest bid might result in inexperienced service providers or those who simply cut costs to win the bid, providing low-quality services and failing to achieve the goals of enhancing building circularity. The TCV project owner team once considered adopting a different bidding method, but their superior agency did not approve it. In the meantime, the B3SH project owner team used the most advantageous method, which ensures that the selected suppliers have the best qualifications and experience to deliver a successful project. Their PSS performances also turn out to be more satisfactory.

Besides the unfitting bidding methods, another key barrier related to the PSS bidding process is the complexity of setting bidding budgets for different building services. The TCV interviewee elaborated that different building services own very different maintenance and repair ways. For instance, repairing lighting fixtures usually involves

merely the replacement of lamps, requiring the least effort and costs. On the other hand, maintaining and repairing air-conditioners are more difficult and involve more building interfaces (e.g., between their piping and interior finishing). Furthermore, like appliances, the new models of air conditioners are released quickly and with higher efficiency, increasing the difficulty of repairing the old-modeled air conditioners due to the limited stock of old components, thus increasing the budget for repair and replacement. The TCV interviewee added that it was very challenging to provide an appropriate bidding budget because they lacked knowledge and experience in providing these building services.

4.3.3 Regarding Construction

Another key barrier that both interviewees pointed out is the miscoordination during the building construction/service product installation phase. The TCV interviewee shared that the installer of these products was their contractor instead of the service provider. Sometimes, the contractor installs those products according to their custom, which differs from the service providers. Furthermore, miscoordination occurred in their late construction phase, i.e., some air-conditioners were misplaced outdoors under poor conditions, which might have caused damage to these conditioners. All these situations lead to difficulty in clarifying the accountability of the product's damages.

4.3.4 Regarding Operation

Another key barrier that both interviewees mentioned is the misbehaviors of the residents. Many residents in these circular housings do not identify with the importance of sustainability. Many regard these public housings as “a temporary dwelling place” rather than their “home.” These narratives result in misbehaviors towards the items provided in their dwelling units, e.g., leaving the windows open while running air conditioning or tampering with thermostats, leading to energy inefficiency and increased wear on mechanical components.

4.4 POTENTIAL FACILITATORS

4.4.1 More Mature PSS Ecosystems

From the TCV interviewee's point of view, they have countered many barriers because the PSS model for building services in Taiwan is at its beginning phase. No companies in Taiwan have ever provided those services via PSS. Very few companies know about this model and are willing to adopt it. This might be related to the limited number of rental housing management firms in Taiwan, leading to the low demand for PSS. As a result, the TCV project owner team has very limited information to refer to for their PSS contracts and bidding documents, and they have a very limited number of bidders to choose from.

Following the rising number of public housings and rental housing management firms in Taiwan, the demand for PSS is likely to increase along with the growth in the supply of better building services via PSS, fastening the

maturity of the PSS ecosystem in Taiwan. Once more knowledgeable and experienced service providers appear in the market, they can offer more diverse and comprehensive services for project owners to choose from according to their demands, fostering healthy competition. More available information will also enable project owners to make better contracts and bidding documents.

4.4.2 More Supportive Governance Systems

As mentioned earlier, an inappropriate bidding method is one of the key barriers to the success of the PSS model. The TCV interviewee said they had to adopt the lowest bid instead of the most advantageous due to the limitation of their superior agency and the Government Procurement Act (GPA) in Taiwan. Pure financial leasing procurement lacks sufficient heterogeneity, and if the amount is not large enough, it is difficult to adopt the most advantageous bid under GPA. Furthermore, the value of leased goods is usually greater than the proportion of services, making it difficult to outsource using a service model. Therefore, he suggested that the current regulation and mindset of the superior need to change to align with the new concepts of circular economy.

As mentioned in the previous section, increasing demand for PSS is critical to fasten the maturity of the PSS ecosystem in Taiwan. Both interviewees advised that the government should propose encouragement or incentive mechanisms to increase the willingness of agencies to allocate relevant budgets, thereby expanding the market. For instance, they could require a certain proportion of leasing procurement based on the project cost amount.

4.4.3 More Coordinated Management Schemes

In order to avoid miscoordination during the building construction/service product installation phase, the TCV interviewee suggested that the product installer should be the service provider instead of the contractor. This can reduce the risk of future disputes about the accountability of products' damages during installation. Nevertheless, this will raise challenges in the project design and construction phase since there are more stakeholders with which to coordinate. The TCV interviewee advised that a Professional Construction Management (PCM) team can facilitate stakeholder communication and ensure better coordination during the construction phase.

4.4.4 More Sustainable Behaviours & Partnerships

Both interviewees agreed that more measures should be taken to help residents identify and adopt a more sustainable lifestyle. Many public housings in Taiwan are certified green and smart buildings. Besides offering their inhabitants a secure place to live, they also provide chances for them to experience a new way of living. These housings have adopted many schemes to enhance community cohesion, e.g., the Youth Innovation Project (YIP) (Yu et al., 2023). The schemes that can be adopted to enhance the residents' awareness of sustainability should be explored.

The B3SH interviewee added that the PSS model that B3SH adopted is business-to-business (B2B) based, i.e., the PSS contracts are signed between the city government and service-provider companies. This model ensures these service providers obtain better loans from banks. However, the frequent and enormous need for product maintenance and repair become a great challenge to these service providers. Some residents have complained that they wish more choices for these services. The B3SH interviewee shared that some of their new public housing projects later adopted a new PSS model, Business-to-Customer (B2C) based, i.e., their contracts are signed between the residents and the service provider. Whether this new model is more successful in terms of its sustainability or financial performance is to be explored.

5 DISCUSSION

This study provides valuable empirical insights into the implementation of PSS within Taiwan's public housing sector, offering a unique perspective from project owners. This contrasts with the broader, more conceptual work of Ghafoor et al. (2023), whose integrative literature review outlines a comprehensive framework for PSS in a circular economy for housing but lacks specific contextual details. While Ghafoor et al. (2024) offer actionable guidance through a multiple-case study approach, our findings complement their work by a localized understanding of the barriers and facilitators at play, specifically within the Taiwanese governance context. Moreover, our focus on project owners addresses a gap between the perspectives of service providers, which are a focus of Ghafoor et al. (2024).

One notable area of convergence across past studies is the identification of barriers to PSS implementation. While this study emphasizes governance-related challenges specific to Taiwan's context, such as contract ambiguities and miscoordination during construction and installation, the research of Ghafoor et al. (2023, 2024) highlights more systemic gaps, including regulatory mechanisms and the need for well-defined intermediary roles to accelerate PSS adoption. Moreover, this study identifies facilitators that resonate with the literature, including supportive governance and collaborative frameworks. However, it distinguishes itself through its emphasis on the maturity of the PSS ecosystem and the heightened sustainability awareness of residents as key enablers. While Azcarate-Aguerre et al. (2022) highlight the significance of technical integration, asset tracking, and performance-based contracts, our research underscores the importance of broader systemic conditions in enabling the successful deployment of PSS in public housing.

6 CONCLUSION

This study explores the implementation of the product-service system (PSS) to foster a circular economy in Taiwan's public housing projects. Data was collected via

interviews with project owners of two pilot projects. These interviews have provided valuable insights into the original motivations and expectations for adopting the PSS model, the actual performances and outcomes, the challenges faced during implementation, and the potential facilitators to overcome these barriers.

Our findings suggest that while the PSS model offers significant promise for enhancing building circularity, challenges persist, particularly in contract clarity and the operationalization of maintenance and repair services. While TCV struggled with its service providers, B3SH benefitted from more successful service execution due to a more qualified supplier selection process (see Figure 1).

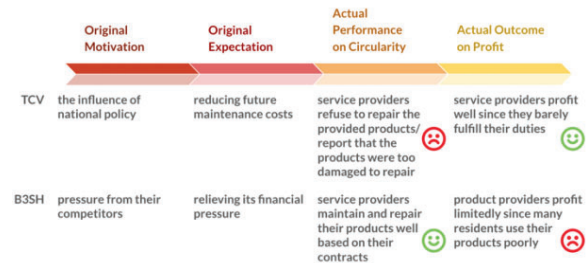


Figure 1: Summary of different motivations/ expectations and actual outcomes on circularity/ profit of two study cases

The study identified several barriers to implementing the PSS model in the two public housing projects (see Figure 2). These included ambiguities in the PSS contracts, particularly regarding the responsibilities for product maintenance and repair, which led to disputes and confusion. Second, the inappropriate bidding methods also hindered the success of the model, with TCV's use of the lowest bid resulting in poor service quality, while B3SH's more advantageous bidding process proved more effective. Additionally, issues such as miscoordination during installation and residents' misbehaviors further complicated the operation of the PSS model.

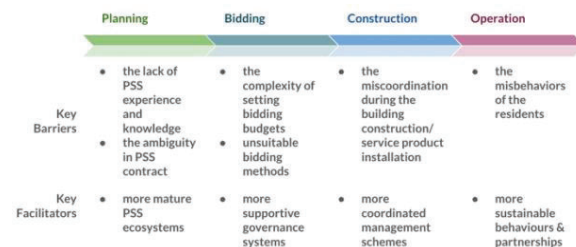


Figure 2: Summary of key barriers and facilitators

The study also identified several potential facilitators that could enhance the effectiveness of the PSS model in future public housing projects (also see Figure 2). Key facilitators include the maturation of the PSS ecosystem in Taiwan, driven by increased demand for public and rental housing and the supply of more experienced service

providers, improving service availability, and fostering healthy competition. Additionally, supportive governance systems could facilitate PSS adoption, including policy adjustments to encourage more advantageous bidding methods and financial incentives. Coordinated management schemes involving service providers directly in installation could reduce miscoordination and disputes. Finally, fostering sustainable behaviors among residents and exploring new stakeholder partnership models could improve the PSS model's overall success in achieving its sustainability and financial goals.

This study offers academic implications by filling gaps in existing research on the integration of PSS in circular housing. While much of the current literature focuses on technical challenges and business models, it remains fragmented and lacks empirical studies tailored to specific housing contexts. This paper contributes new, context-specific insights into the adoption and implementation of PSS in Taiwan's public housing sector, particularly on the role of project owners, which has been insufficiently explored in prior research. On the non-academic side, the findings provide actionable recommendations for industry practitioners and policymakers. The study underscores the importance of clearer governance frameworks and informed decision-making in adopting circular business models, offering guidance for scaling the adoption of sustainable practices in public housing and facilitating broader transitions towards a circular economy in the building industry.

Our future research will further expand the understanding of the implemented PSS by incorporating interviews with service providers and occupants to gain a more holistic view of the system's performance. Engaging with service providers will illuminate the challenges of delivering services under PSS contracts. At the same time, feedback from occupants can offer insights into the user experience and sustainable behavior. Additionally, exploring new contract models, such as Business-to-Customer (B2C), and the dynamics between new stakeholders in this model could offer valuable insights into its potential for enhancing sustainability and financial performance. Another key area for further study could also include examining how circularity can be achieved through the actions of product wholesalers, particularly in relation to the value derived from materials within default products. While the connection to circularity is more apparent with product manufacturers, understanding how wholesalers perceive and leverage materials as a source of value is crucial. Finally, developing a maturity assessment framework for project owner organizations will be valuable in evaluating the readiness of organizations to implement and scale PSS models effectively. This framework could guide organizations in assessing their capabilities and aligning resources to ensure the success of circular economy initiatives in housing projects.

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