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LEAN CO-ACTING WITH CIRCULARITY? AN INVESTIGATION IN PRODUCT-SERVICE SYSTEMS IN RENTAL HOUSING

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ABSTRACT

Circularity is positioned as an alternative model to achieve sustainable prosperity. Lean construction highlights not only building delivery with less but also contributing to sustainable development. However, lean is criticized for reducing waste only within organizational boundaries while neglecting the impact of waste beyond the boundaries. On the contrary, circularity originates to reduce waste in the system and is currently seeking approaches to implement waste reduction in circular production. To speed up the transition to sustainable resource consumption, the co-act between lean and circular construction seems evident. This research studies resource consumption in product-service systems (PSSs), which are acknowledged to reduce resource consumption. This research first assesses the ability of PSSs to slow and close the loops. After this, the research discusses the complementarities of circularity and lean to co-act toward the same goal. The multiple case studies demonstrate that PSSs have the potential to slow and close the loops. However, PSSs are not inherently circular, but each PSS needs to be designed to be circular system-by-system. Furthermore, the theoretical discussion encourages lean to co-act with circularity. The PSSs provide a system view to lean: to reduce current and future waste and to avoid value losses in multiple life cycles.

KEYWORDS

Circularity, servitization, product-service system, building components.

INTRODUCTION

In recent years, circularity has been introduced as means to sustainability in many scholars, including the built environment and construction studies (e.g., Benachi et al. 2021, Munaro et al., 2020; Ghaffar et al., 2020). For example, Chen et al. (2022) stated that circularity in construction could be "a new model to retain the value of resources and to prevent the use of virgin materials and waste outputs, not only by recycling and reusing of materials but also primary by reducing the need for resources". Furthermore, circularity in general is proposed to be the transformative model for sustainable prosperity (Azevedo et al., 2017; Lacy et al., 2020). Similarly, lean construction literature highlights not only building delivery with fewer resources but lean delivering sustainable prosperity (Huovila & Koskela, 1998; Novak, 2012a; Novak 2012b). At the same time, product-service systems (PSSs) are recognized as an alternative model to reduce resource consumption while ensuring economic growth (Lacy et al., 2014). In

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PSSs, commonly known as Product-as-a-Service (PaaS), the customer pays for access to the product and its functionality, which in traditional models are acquired through ownership. When the PSS provider stays the owner of the product, the PSSs provider is incentivized to extend the lifespan and usage of the product and its materials, and to reduce costs (Halme et al., 2004). However, it remains unclear to what extent PSSs are circular (Fernandes et al., 2020; Van der Laan & Aurisicchio, 2020).

PSSs are not widely studied in lean construction literature although servitization in general has started to receive more attention in the construction sector due to the paradigm shift "from delivering a product to satisfy the user needs" (Liu et al. 2021). Servitization in the construction sector is mainly implemented either in the operation phase (such as in maintenance, energy management, or in security), or in production servitization, where "construction activities are conceptualized as construction services" (such as material supply services or computing services) (Liu et al., 2021). To summarize, servitization adds value to the existing products, while PSSs utilize services to contribute to dematerialization.

Although waste reduction is one of the key concepts in lean, lean is criticized for focusing on "the immediate usage of the resource within a specific process" (Nadeem et al., 2019) and missing the system level, i.e., the environmental and economic impact beyond the organizational boundaries (Schmitt et al., 2021). Circularity does take the system perspective when optimizing resource usage from one life cycle to another while (Nadeem et al., 2019). On the other hand, current circularity research is seeking approaches to reduce resource consumption on the process level. Schmitt et al. (2021) stated that lean could "increase the efficiency of all circular flows, thus greasing the wheels of circular economy". For example, Kurdve and Bellgram (2021) studied how lean can operationalize circularity on the shopfloor level. The general complementarities between circularity and lean encourage further investigation of the co-act between circularity and lean construction.

To summarize, both lean and circularity have a common interest to reduce resource consumption. PSSs are argued to reduce resource consumption, but it remains unclear to what extent PSSs are circular. This leads to a twofold aim. First, to assess the ability of PSSs to slow and close the loops according to the circularity principles and second, to discuss the complementarities of circularity and lean to co-act towards the same goal in PSSs. A multiple case study approach was selected to analyze the ability of PSSs to slow and close loops in Dutch rental housing. The Netherlands is experiencing an urgent housing crisis. It is estimated that 900,000 homes need to be built before 2030 to arrange for homes for the increasing population and address the current housing shortage (Ministerie van Binnenlandse Zaken en Koninkrijksrelatie, 2019). At the same time, the Netherlands has set an ambitious goal to improve the energy efficiency of the current housing stock and to develop a circular economy by 2050, and to reduce the consumption of raw materials by 50% by 2030 (Government of the Netherlands, 2016). This also applies to the Dutch housing sector. The ambition to expand and improve the housing stock in the Netherlands can lead to a huge increase in resource consumption but also pose an opportunity for innovation, such as PSSs, and incorporating circular economic principles in residential buildings.

The remaining paper is structured into four parts. First, PPSs are presented including the four models: input-, availability-, usage- and performance-based models. After this, the method section presents the multiple case study method and the selected PSSs. The results outline the ability of PSS to slow and close the loops according to the circularity principles case-by-case and across cases. Finally, the discussion focuses on interpreting the results and theorizing complementarities between lean construction and circularity in PSSs.

PRODUCT-SERVICE SYSTEMS

Historically, the target of the companies has been to sell their products to their customers. In the 1980's and 1990's, many companies searched for solutions to create and capture more value in the competitive market. Within this search, some companies decided to start selling products and services together to better serve their customers. This was discussed as 'servitization of businesses' (Vandermerwe & Rada, 1988) and it is currently gaining increased attention in the race towards circularity due to its ability to reduce resource consumption.

In the traditional economic models, producers are typically motivated to reduce cost via mass production: by providing standard quality without the incentive of providing products with long lifespans (Mont, 2002). Another typical quality in mass-production is that the maintenance responsibility of the product is transferred to the buyer at the moment of the purchase. This all leads to resource-intensive production and consumption. From PSSs perspective, the circular incentives aim to reduce resource consumption through two approaches. In the first approach, the customer owns the product, and the producer offers maintenance and a take-back program for the customer. This approach does not guarantee that the product will be returned to the producer (Van Ostaeyen et al., 2013). In the second approach, the ownership of the product remains for the producer and the customer has access to use the service. This type of ownerless consumption ensures that the product is returned to the producer (Van Ostaeyen et al., 2013). When the producer sees the returned product as an asset and the material is recycled in the next production line, the "take-make-dispose" logic is broken without risking economic growth.

There are four principles to evaluate the circularity ability of PSSs as established by Bocken et al. (2016). The first two principles represent the product's capability to slow and close loops. Product slowing the loops refers to prolonging the use period of the product (Bocken et al., 2016). In the PSSs context, this typically refers to the product's capability to receive preventive maintenance. Product closing the loops refers to reusing the materials through recycling (Bocken et al., 2016). The authors (2016) list three design strategies to close the loops: design for a technological cycle, design for a biological cycle, and design for dis- and reassembly. These strategies enable easy use of the product components or material in the next loop. The last two principles refer to the ability of business models to slow and close loops. When a business model is slowing the loop, it enables a long product life span and reuse of products (Bocken, et al. 2016). For example, the business model allows that the product is used to its maximum, or that the residual value of the product, as Bocken et al. 2016 call it, is (fully) exploited in the same or in another PSS. Finally, the circular business model closes loops, when being able to capture *"the value from what is considered in a linear business approach, as by-products"* (Bocken et al., 2016). In PSSs, this means that the product or its components, and material are recycled.

Four types of PSS systems can be distinguished (Van Ostaeyen et al., 2013): input-, availability-, usage- and performance-based models each characterized by different fee structures and levels of servitization (Figure 1). The servitization level is the lowest in input-based and the highest in performance-based models. Next, these four PSS models are briefly introduced in a housing context.

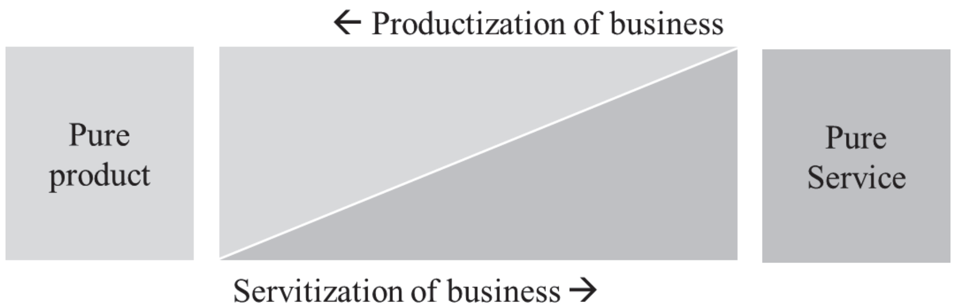

Figure 1: Servitization and Productization (in Parker (2021), based on Vandermerwe & Rada (1988), Tukker (2004) and Leoni (2015).

INPUT-BASED MODEL

In the input-based model, the housing provider owns the product and pays service fees to the PSS provider for the services that are needed to operate the product. The services may comprise, for example, product maintenance, supply of consumables, product's pay-back program, and consultancy services for the user to ensure that the product is used efficiently and effectively (Tukker, 2004). A typical example from the housing sector is a heating boiler that the housing provider purchases, including an agreement for maintenance and inspection and a take-back program at the end of the product's lifespan.

AVAILABILITY-BASED MODEL

In the availability-based model, the PSS provider owns the product, and the housing provider leases it. The fixed recurring fee paid by the housing provider includes the product's availability regardless of how much it is used. In addition, the fee needs to cover the maintenance and repairs that keep the product in operation (Tukker, 2004). Furthermore, for the duration of the model, the availability is only pertained to the one that pays, meaning that the product or is usage is not shared. A typical example in the housing sector is a kitchen that is owned and maintained by the PSS provider and leased by the housing provider.

USAGE-BASED MODEL

In the usage-based model, the PSS provider owns the product, and the housing provider leases it. Compared to the previous model, the major variation is that the housing provider pays for the usage of the product, not for the product's availability (Van Ostaeyen et al., 2013). A typical example in the housing sector is the lease of an elevator: the housing provider pays a lease based on the annual distance traveled by the elevator and the PSS provider retains the ownership and keeps the product in operation.

PERFORMANCE-BASED MODEL

In this model, the housing provider pays a leasing fee to the PSS provider only when a desired performance is attained. In this model, the PSS provider, as the owner of the product, adjusts and maintains the product to attain the required performance level (Tukker, 2004). A typical example of this type of model is companies that do not only provide heating and cooling equipment, but instead provide a defined indoor climate (temperature, humidity, and indoor air quality) (Tukker, 2004). Performance-based housing products were not yet identified within the housing market; thus, this model was excluded from the empirical research.

RESEARCH METHODS

MULTIPLE CASE STUDY APPROACH

PSSs in buildings could target products or services at multiple building layers. A distinction for building layers was discussed by Brand (1994): structure, skin, services, space plan, stuff, and site. Different building layers have different duration of service lives and offer different functions that a building user could enjoy and pay for. For example, renting furniture in an empty home would target the building layer 'stuff', but could be changed based on users' taste in style. On the other hand, the choice of stone or wood for structural and insulation, could not be changed by every new tenant of a buildings' whims. Therefore, the implications for choosing a workable PSS may vary with targeting these different building layers.

To analyze a variety of products from multiple building layers and a variety of PSS models (including input, availability, and usage models), our research follows a multiple-case study approach. Multiple case study design allows replication (Yin, 2013). In this research, this means that the circularity of PSSs is studied among variety of products and business models to make analytical conclusions about the capability of these systems to slow and close the loops. This replication ensures that similar types of findings are found if they exist. Table 1 summarizes the case study selection criteria.

Table 1: Case study selection.

		Cases						
		A	B	C	D	E	F	G
Represents a variety of PSS models:	Input	x						
	Availability		x	x	x			
	Usage					x	x	x
Possible to include both perspectives: housing provider and PSS provider		x	x	x	x	x		

Seven cases were selected to cover the three PSS models: input-, availability- and usage-based models, based on a variety of building layers and PSS types. The size and market position of the housing provider and PSS provider vary per case. In five cases (cases A-E), two interviews were done per case: an interview with the representative from the housing provider and from the PSS provider. In the two cases (cases F-G), the representative from the housing provider was unavailable and the interviews were limited to the representative from the PSS provider. All 12 interviews were conducted in spring 2021 and they were recorded and transcribed for the analysis.

INTRODUCTION TO THE CASES

In this section, all the cases are briefly introduced. In case A, a PSS of two existing elevators in a residential building of 78 apartments is studied. The housing provider owns the elevators and has a 5-year service contract with an extension option with the PSS provider. The housing portfolio of the housing provider includes 10.000+ rental homes, and the housing provider has used PSS before in their portfolio.

In case B, PSS kitchens are studied in a project where an office building was transformed into housing. 15 of the PSS kitchens are based on a lease-to-own service contract with a pay-back program. The housing provider has paid an installation fee to the PSS provider and is also responsible for the recurring service payments. One kitchen is owned by the PSS provider (as a pilot) and the housing provider pays a service fee for it. The housing provider is a small, young organization in the social housing sector managing a 5-year-old, small portfolio of rental homes at the time the case study was conducted. This was their first PSS purchase. The PSS provider is also a beginner in the field and at that moment has installed 10 PSS kitchens.

Case C is also a transformation case from office to housing. In this transformation project, an availability-based model is used for 130 windows. The windows are owned by the PSS provider and the housing provider only pays the recurring service payments – no installation fees or down payments are part of the deal. At the time, the housing provider had a portfolio of 10+ housing buildings and had operated for 12 years. This was their first PSS project. The PSS provider had a long business experience (30+ years), but this was also their first PSS contact.

In case D, the study object is the PSS of a battery storage system in a 50-apartment housing building. The PSS provider owns the battery storage system. The housing provider has paid an installation fee and is responsible for the recurring service payments (no down payments were included). The housing provider has a large portfolio of social rental homes (16.000+), and the PSS provider has sold more than 100 PSS batteries.

Case E is another elevator case study but with a different PSS model: 14 elevators are installed in a new construction project including a total of 485 homes, of which 200 are rental homes owned by the housing provider. In this case, the PSS provider is the owner of the elevators, and the housing provider only pays recurring service payments based on the usage of the elevators – there are no down payments or installation fees for the housing provider. The PSS provider has sold the product (i.e., elevator) for more than 65 years and since 2017 with the PSS model. Their PSS portfolio includes 200+ elevators.

Case F includes the PSS of a heat pump in a housing building including 27 homes. The PSS provider owns the heat pump, and the housing provider only pays recurring service payments based on usage – there are no down payments or installation fees for the housing provider. The housing provider is an association that owns and rents the residential units for long term. At the moment the case study was conducted, the PSS provider has sold this product for 2+ years and installed 3 PSS heat pumps.

In case G, solar panels are installed on the existing residential buildings. The PSS provider owns the solar panels, and the housing provider only pays recurring service payments based on the usage – there were no down payments or installation fees for the housing provider. The housing provider is a long-term owner in social housing and the PSS provider has at that moment sold their PSS panels for 9+ years.

RESULTS

The results are first presented case by case including table 2, which summarizes each case. After this, the results of the cross-case analysis are discussed.

SINGLE CASE STUDY ANALYSIS

In case A, the analysis identifies that circularity is supported through preventive maintenance of the elevator. The input model encourages preventive maintenance, and this maintenance extended the lifespan of the elevator. The interviewee from the housing provider stated: "*They* [=the PSS provider] *have the diagnostics, and they can support us in making the right decisions. And they can also know the equipment that we're replacing and parts we're adding to make the useful life longer*." In other words, the product can receive preventive maintenance and the PSS model offers that maintenance. This slows down the resource loops.

In case B, the analysis finds many circular aspects. The kitchen design itself allows easy repair and maintenance that is also provided through the availability-based PSS model. This means, for example, that the fronts are changed after 5 years if the kitchen is used intensively. In other words, the product and the availability model slow down the resource loops. In addition, the disassembly design of the kitchen and the PSS model allowed the product to be looped into another destination by extending the product value. The PSS provider in case B stated: "*For* *the appliances, indeed, it's all about companies, eventually taking back their product and using it in the highest value possible at the stage. That's either directly using it again, refurbishment, remanufacturing, and you go down the R-ladder in the end, recycle. And that is something that we put in the contract.*" This indicates that the product and the PSS model contribute to slowing and closing the loops.

In case C, the analysis also identifies many of the circular aspects. First, the PSS provider was responsible for keeping the quality of windows as high as possible. The representative of the PSS provider said: "*We have a long-term performance contract with them to keep the quality as high as possible so that we can enlarge the lifespan of the materials*." This means that the product itself and the related service slow down the loops. In addition, both the housing provider and the PSS provider highlighted that the product and/or materials are looped again after the disassembly. For example, the representative of the housing provider stated that "*You push the manufacturer to think about their product, how is this going to be disassembled, how it is going to be brought back in the loop again*" and the representative from the PSS provider stated that *"...100% must be recycled and reused. […] We set up the new brand, in the DNA is already embedded that we just reuse it till the end*.". This means minimized extraction of natural resources: the business model and the product are closing the loops through looping the products and/or materials and through a principle that only looped products and/or materials are allowed to be used.

In case D, it was not found that the product itself (i.e., the battery) is contributing to slowing or closing the loops, but that the business model is. The availability-based PSS allowed that the PSS provider exploits the residual value of the batteries: the remaining lifespan of the replaced batteries was utilized in smaller systems, where they were still suitable for use. This utilization extended the lifespan of these batteries, i.e., slows down the loops.

In case E, the analysis identifies many circular aspects to slow down and close the loops. As in case A, in this case the lifespan of the elevator is extended through advanced maintenance. In other words, the PSS extends the lifespan of the elevator (slowing the loop). The business models are also aiming to slow down the loops by utilizing the residual value of the materials, including the creation of reverse logistics. The estimation was that "*if these materials are not available anymore, they will become more expensive*", as the representative of the PSS provider in case D stated it. In addition, the product itself and the usage-based PSS, in which the PSS provider is the owner of the elevator, contribute to closing the material loops. It was stated by the representative of the PSS provider that approximately 90% of the elevator parts are recycled and the remaining 10%, that is electronic parts, are not. This contributes to closing the loops.

In case F, the analysis does not identify any circular aspect of the product or the related business model. The business model does provide preventive maintenance, but this maintenance is not expected to extend the lifespan of the heat pump. The material of the heat pump is also not reused or recycled. The PSS provider stated: *"It is very difficult to take out the materials. We've asked now, the heating suppliers, to make a system which can be [a] modular system where you can take out some blocks in 15 years and put in back another, which they do, of course, but they don't do it with the vision of how to reuse [it]."*

In case G, the analysis finds only one aspect that supports circularity: preventive maintenance expands the lifespan of solar panels. The solar panels are designed for preventive maintenance but not for disassembly. This means that the residual value is not utilized and circular input is not generated. The representative from the PSS provider stated: "*Either the solar panels are very good, and everything is normal, so we keep on doing it […]. Or we reinvest exactly after 20 years, put new panels on, and everything is continued […]*.".

Table 1: Summary of the case studies.

	Cases						
	A	B	C	D	E	F	G
Product: slowing loop	x	x	x		x		x
Product: closing loops		x	x		x		
Business model: slowing loops	x	x	x	x	x		x
Business model: closing loops		x	x		x		

CROSS-CASE STUDY ANALYSIS

In slowing down the loops, preventive maintenance seems to play a key role in the PSS cases. The business model provides preventive maintenance and extends the lifespan of the product. In addition, due to the circular product design, the product can receive predictive maintenance. Together these aspects slow down the loops. This was found in five cases out of the seven (in cases A, B, C, E, and G). Case D did not follow this logic in slowing down the loops. In case D, the loop was slowed down through the business model that kept the ownership of the product with the PSS provider, who could, after replacement, use the remaining lifespan of the product in another system with another client. This means that the lifespan of the product is used to its maximum, i.e., the business model (not the product) slows the loop.

In closing the loops, the disassembly or deconstruction ability of the product was instrumental in the easy use of the product and its materials in the next loop. In addition, the business model was designed to catch the product from one loop and to deliver it to another through recycling (cases B, C, and E). Contrary to expectations that the usage-based model closes the loops effectively, as proposed for example by Ostaeyen (2013), cases F and G did not contribute to closing the loops: the product, nor the usage-based PSS, were designed for reusing the product or its materials.

To conclude, PSSs have a high potential to be circular when the product and the service in the system are designed for circularity. However, not all PSS are inherently circular meaning that the use of PSSs does not automatically lead to circularity.

DISCUSSION

Within the highlighted role of circularity in sustainable development, PSSs are commonly accepted business models to reduce resource consumption. Based on the existing literature, it was expected that the utilized circularity principles are increased when moving in the PSS axis of input-availability-usage. However, this was not the case in this research, where the 7 PSS cases were conducted and analyzed. The results imply that the PSSs are not inherently circular, but each PSS needs to be designed to be circular system-by-system. Similar results can be found in the literature (e.g., Blüher et al., 2020; Tukker and Tischnener, 2006). The results do not imply that PSSs should not be used to contribute to achieving circularity but that the PSSs need careful design at all the stages of design.

This paper claims that PSSs provide an example for circularity and lean construction to co-act towards the same goals – to reduce resource consumption and to deliver sustainable prosperity. Benachio et al. (2021) studied "the interactions between lean construction principles and circular economy (CE) practices". We see these interactions as natural interfaces for circularity and lean construction to co-act and supplement each other. In their paper, Benachio et al. (2021) recognize the CE practice that is studied in this paper: ownerless consumption, where the manufacturer stays the owner of the material. Benachio et al. (2021) refer specifically to the moment after the end-of-life of the first building meaning that the manufacturer takes responsibility for and makes an opportunity at the first looping moment. In PSSs, the system can take on this responsibility, when, as the cases A-E and G illustrate, the product and/or the business model are designed for that. For example, in case C the manufacturer carried on the responsibility of the first loop of the windows as was also done in case D with the battery although the product itself did not support circularity.

After studying circularity in PSSs, the discussion is moved to postulate key complementarities between circularity and lean in PSSs. In general, lean and circularly deal with two key concepts – value and waste – but have major differences in embracing these concepts. Complementarities can be explained via these concepts.

In lean, value is defined by the customer (e.g., Womack and Jones, 1996; Ballard et al., 2001; Salvatierra-Garrido et al., 2008) and the flow is made at the pull of the customer (e.g., Womack et al., 1990; Howell and Ballard, 1998). In circular terms, material is seen as a source of value, and the value of resources is used to the maximum in the life cycle of the material (Nadeem et al., 2019; Bocken et al., 2016; Schmitt et al., 2021). Nadeem et al. (2019) interpret this as a limitation and argue that this kind of "highest utility of resources all the time" accelerates the resource depletion. In closed loops, the circular philosophy highlights upcycling meaning that in recycling and reusing the value of the material should be retained or improved (Bocken et al., 2016). To conclude, the concept of value in circularity does not include the customer's perspective and the concept of value in lean does not include the maximum use of the material value.

In PSSs, the two value concepts complement each other. According to Romero and Rossi (2017), PSSs deliver value-in-use. From a lean perspective, the PSS extends the concept of value from one life cycle to another, for example by utilizing the residual value of the product in another system (such as in cases D and E). In terms of lean, the use of the residual value would avoid future value losses. From a circularity perspective, PSSs ensure that only the needed resources are consumed. PSS makes sure that the resource is consumed at the time it is needed (i.e., at the pull).

Similarly, waste is seen differently. In lean, waste refers to the use of more than needed and unwanted output (Bølviken et al., 2014). Furthermore, the non-value-adding activities are removed through continuous improvement (in Japanese kaizen) (Imai, 1997). Waste in circularity has another meaning. In a closed-loop system, waste from one life cycle is used as a resource (i.e., source of value) in another life cycle. Wasted resources are transformed into new forms of value, as outlined in Bocken et al. (2016). By slowing the loops, the prolonged use postpones the end of the resource's life. When products and parts are designed for dis- and reassembly, they are easily looped in other cycles (Bocken et al., 2016).

In PSSs, the waste concepts complement each other. The concept of waste from lean can improve the operational efficiency of PSSs. Romeno and Rossi (2017) have studied circular lean PSSs and they claim that lean can eliminate "waste in the manufacturing activities and services operations that affect the PSS efficiency". Unfortunately, circular systems do not widely acknowledge that resources are wasted in the circular processes themselves. Korhonen et al. (2018) stated that "all CE-type initiatives, projects and activities generate environmental impacts and consume resources". In the PSS cases, the production of circular elevators, windows, or kitchens consumes resources, as does the preventive maintenance of these products. Lean focuses on throughput optimization on the shopfloor (Schmitt et al., 2021). Therefore, the concept of waste lean can complement circularity by operationalizing waste reduction on the shop floor and increasing the operational efficiency of the circular production system itself (Schmitt et al., 2021).

The circularity of PSSs complements the concept of waste in lean. PSSs provide a system approach to lean, not only to reduce resource consumption in the current process but from one life cycle to another. This means that future waste is reduced, when the product is designed for dis- and reassembly and thus easily reused, recycled, or remanufactured. To be circular, lean needs to build its reserve production practices.

CONCLUSIONS

Within the highlighted role of circularity in sustainable development, PSSs are commonly accepted business models to reduce resource consumption. In lean construction, PSSs as such are not highlighted. Therefore, this paper first assessed the ability of PSSs to slow and close the loops; and after this, discussed the complementarities of circularity and lean to co-act towards the same goal. A multiple case study approach was followed.

The case studies imply that PSSs are not inherently circular, but each PSS needs to be designed to be circular system-by-system. This does not imply that PSSs should not be used to contribute to achieving circularity, but that PSSs need careful design at all the stages of design. Furthermore, the theoretical discussion encourages lean to co-act with circularity in PSSs. PSSs provide a system view to lean: not only to reduce resource consumption and deliver value in the current processes but also from one life cycle to another. This would mean that future waste is reduced and that the value losses are avoided when the value of resources is fully exploited. For circularity, lean offers an approach to reduce resource consumption in the circular processes themselves by operationalizing waste reduction on the shop floor. Furthermore, the integration of the customer's perspective into the concept of value ensures that circular products are used at the pull of the customer. It is advisable to investigate these complementarities not only systematically further within a PSS but also between PSSs.

The paper has its limitations. First, the research on PSS types in the building context is quite novel empirically, rendering only a handful of cases that can be easily studied. The case selection is limited to the input-, availability- and usage-based PSS models since no performance-based models were available for this study. Secondly, this research is limited to qualitative assessment of resource consumption based on interviews. In future studies, quantitative data are needed to assess the effectiveness of PSSs in reducing resource consumption. Thirdly, as many organizations are still new to the PSS workings, the results may themselves have an impact on how practitioners are still learning and working with these business models. Fourthly, the notion that the design of the model has an influence on its ability to achieve circularity, implies that more design choices need to be explicit for this relation to be studied more targeted. Lastly, the lean analysis was not part of the original data analysis in the cases. This limited the lean discussion on the theoretical level urging to continue studying the topic with real cases in the future.

Recommendations resulting from the study include a few notable directions. First, as more applications in practices are piloted and upscaled, research studies like these need to keep pace with the collective learning, if we are to generalize the true nature of PSS on circularity. Second, more emphasis in future studies needs to be performed on the specific design choices for PSS applications, the object, and the level of achieved or intended circularity. Lastly, due to circularity and lean acting alone towards the same goal, it would be interesting to further explore the co-acting possibilities between lean and circularity in the construction sector. Alone the journey towards delivering sustainable prosperity might be faster, together we might go further.

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