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Integrated façades as a Product-Service System – Business process innovation to accelerate integral product implementation

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Abstract

The Circular Economy (CE) attempts to realign business incentives, across all fields of human industry, to support the preservation of raw materials within closed economic loops. Within this conceptual frame, Product-Service Systems (PSS) combine the use of tangible products such as building technologies, with intangible maintenance and monitoring services, to enhance the delivery of valuable performance while limiting the use of materials and other finite resources. This paper explores the potential for the application of CE and PSS organisation principles in the delivery of Façades-as-a-Service. It explores how the benefits brought about by this way of thinking - lower initial capital requirements, material ownership retention by suppliers, and long-term interdisciplinary collaboration - could lead to a more efficient façade construction industry, while accelerating the rate and depth of building energy renovations.

Within the current process for designing, manufacturing, and operating façades there is a gap between supply-side discoveries and demand-side needs, which hinders the implementation of resource-efficient façades. Façade-leasing as a form of product-service system keeps suppliers committed, throughout the building's service-life, to safeguard optimum performance in operation, while actively stimulating clients to adopt innovative technical solutions.

The paper elaborates on both supply-side façade innovations and the demand-side conditions necessary to implement such business models, and also explores the costs and benefits of product-service systems as new collaboration models to align supply and demand incentives. It builds upon the research project "Façade leasing" (Azcárate-Aguerre, J.F., 2014) and combines knowledge about façade design and engineering (supply-side approach) with the knowledge about client needs, performance criteria, and willingness to pay (demand-side approach). The research methodology includes a literature review and expert interviews, integrating both theory and practice.

This paper argues that a Product-Service System approach to façade design, construction, operation, and renovation could accelerate the rate and depth of building energy renovations. It could also provide incentives to supply- and demand-side stakeholders, to implement Circular Economy principles through new models of product ownership, service contracting, and performance delivery. It aims at establishing the general conceptual frame of a Product-Service System for leasable façades, setting the basic parameters to be taken into account when designing a PSS-based business model, and formulating its value proposition.

Keywords

product-service systems (PSS), façade-as-a-service, leasing, resource-efficient innovation, integrated façades, circular economy

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1 INTRODUCTION - HOW DOES THE CONSTRUCTION PROCESS HINDER THE IMPLEMENTATION OF ENERGY SAVING MEASURES AND COMPONENTS?

The last few decades have seen an exponential development in the field of energy conservation and generation technologies within the construction sector. Goals for the reduction of CO₂ emissions, established by the EU for the years 2020 and 2050, have set a strong regulatory frame for the implementation of such technologies in all fields of architectural and infrastructural development. As a result, many organisations with large real estate portfolios – such as universities, hospitals, and financial institutions – have signed agreements in the past decade to reduce their ecological footprint and stimulate resource-efficient projects (Den Heijer & Teeuw, 2010; Joustra, de Jong, & Engelaer, 2013; ABN AMRO, 2014; ING, 2015). However, the mass-market implementation of energy-efficient products is being negatively affected by the traditional business and supply processes that dominate the construction industry (Vrijhoef, 2011). Innovative business models and contracting mechanisms are required to support and accelerate the market absorption of energy-efficient technologies in the industry, share the performance risks (and benefits) of innovative products, and enhance the financial accessibility of performance-based renovations (Gondrie, 2015). This would upscale the impact of upcoming technologies on the reduction of CO₂ emissions, by facilitating their market-wide implementation. In other words, innovative business and management processes are required to act as a catalyst for the accelerated implementation of innovative technological products.

Despite the current technological capacity to produce energy-neutral and even energy-positive buildings (Marszal & Heiselberg, 2011) the real-life application of these technologies is still limited to a relatively small segment of high-performance, high-cost, iconic, and experimental constructions (Banfi, Farsi, Filippini, & Jakob, 2008). Low-energy buildings – though highly significant from a scientific and marketing perspective – are still a small fraction of the European building stock. The main hindrance to the wider utilisation of such systems lies in the incentive structure that dominates the industry, as short-term stakeholders are offered no direct incentives from the long-term operational benefits provided by their products (Van Nederveen & Gielingh, 2009; Vrijhoef, 2011).

Direct operational benefits from energy savings must be complemented by the multi-stakeholder incentive structure proposed by a Circular Economy systemic approach. In the current, product-centred transaction structure, stakeholders involved in the construction and operation of a building have short-term participation in the project based on the sale of components. A transition towards a service-based structure, founded on the long-term collaboration between project partners with shared performance goals, will more effectively create shared value while improving a building's performance and ecological impact from an energy and raw material consumption perspective.

Many of the theoretical assumptions presented in this paper have been extrapolated from better-documented examples belonging to other manufacturing industries, as this is a relatively unexplored topic in the construction industry. This study builds upon these examples to establish a value proposition for new models of collaboration, by outlying the theoretical costs and benefits of a long-term, Product-Service System (PSS) for the delivery of Façades-as-a-Service. This is done from the point of view of both supply and demand side stakeholders. In order to evaluate this proposition, we combine, on the one hand, a Building Technologies approach to describe upcoming technological products, as well as their potential impact on a building's energy performance. On the other hand, we assess, from a Real Estate Management perspective, the value these product-service combinations could represent for a (client) organisation. This is based on their contribution to the organization's functional, financial, strategic and sustainability/energy goals (Den Heijer, 2011; Den Heijer, 2013) (Fig. 1).

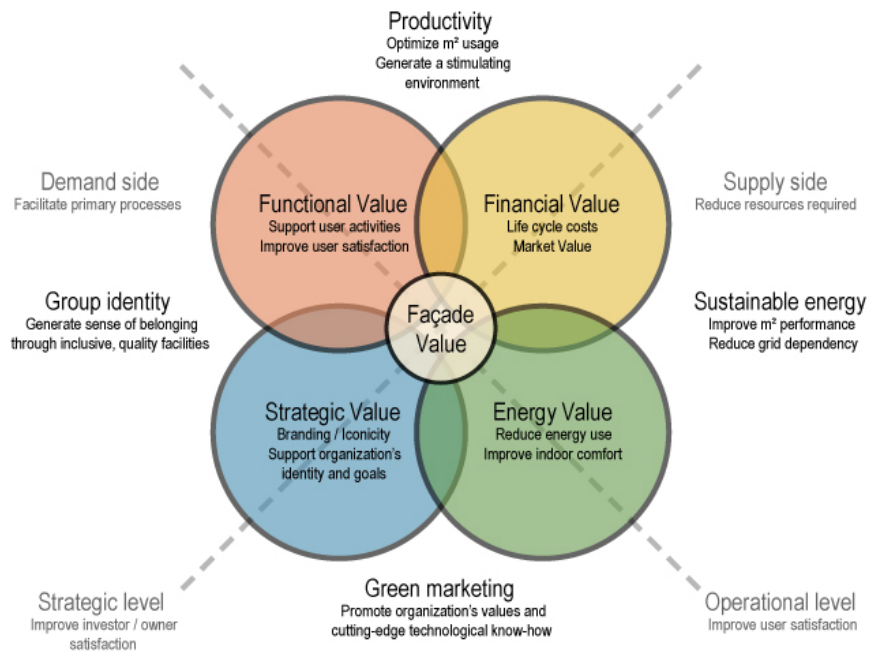


FIG. 28 "4-value" performance criteria for determining added value for clients and end-users of real estate. Adapted from Den Heijer, 2013 (based on real estate management theory (Heijer, 2011))

This paper proposes that the general focus on short-term financial gains (or losses) that currently dominates decision-making, often results in missed opportunities to collaboratively extract long-term value in the functional, strategic, and energetic fields, while also preventing the implementation of circular resource management and conservation strategies. It explores the ways in which the current supply process hinders the application of new, and more efficient, building products and technologies (section 2). It then explores the supply-side challenges and opportunities (section 3.1), as well as the demand-side requirements and interests that must be taken into account (section 3.2) in order to determine the brief for new business-to-client models that encourage innovation (section 4). The objective is to outline the changing role of stakeholders, the added value for demand and supply sides, and, lastly, to define further necessary research along these lines.

2 PROBLEMS IN THE CURRENT CONSTRUCTION PROCESS

The current construction industry is characterised, as are many other manufacturing industries, by a strong linear process (Vrijhoef, 2011; Joustra, de Jong, & Engelaer, 2013). The flow of materials, services, and knowledge through the supply chain is largely interrupted at every step of the process, as long-term collaboration between supply tiers, contractors, and clients is hardly promoted by current contracting methods (Vrijhoef, 2011). The general tendency to look at buildings as "finished products" rather than "ongoing processes" leads to an overall short-sightedness when defining the most efficient operation and end-of-service scenario design for the construction and the materials that compose it.

A failure to define long-term goals that can be shared by all stakeholders (on the supply and demand sides), results in a process that assigns a high value to materials - as materials and components are the elements being traded between stakeholders - while underestimating the value of services (or capabilities) delivered by or through such products. We have identified two primary mechanisms

embedded in the construction process that contribute to a fragmented supply-chain and a slow technological progress curve. These are further described below as: 2.1 Business and supply mechanisms, and 2.2 Technological innovation mechanisms.

2.1 BUSINESS AND SUPPLY MECHANISM

The rate of innovation, development, knowledge transfer, and implementation - in other words, the technological life cycle - of the construction industry is relatively slow. This section elaborates on those negative circumstances, which lie within the business and supply practices of the construction industry: (A) The industry structure, and (B) The small scale of supply companies.

A. The industry structure -When compared to other manufacturing industries (such as automotive and consumer electronics), the construction industry stands out for its general lack of central coordination (Van Nederveen & Gielingh, 2009; Vrijhoef, 2011). A central driving force, in this context, is defined as a stakeholder with incentives to optimise the entire production process - from design through fabrication, operation, and end-of-service reprocessing - who has clear leverage on suppliers and subcontractors, and therefore the power to reshape the entire supply chain towards more efficient or sustainable practices. As a reference, automobile manufacturers act as central driving forces throughout the entire process from the design to the collection/reprocessing of a car, even when they may not be necessarily responsible for individual steps in the process such as designing and manufacturing individual components, or providing aftermarket servicing and maintenance. Their crucial role in the production of the car, in terms of design, assembly, branding, and even financing, provides them with an important leverage to re-define their processes and demand suppliers to follow their guidelines. As established by the principles of "lean manufacturing" (Womack, Jones, & Roos, 1990) this long-term relationship between the product assembler/marketer and component suppliers promotes innovation and efficiency by setting common and extended performance-oriented goals throughout the supply-chain.

In the construction industry, however, there are two mayor conflicts that prevent the application of such processes. On one hand, the supply-chain, consortium, and contracts differ from project to project (Vrijhoef 2011). They are as customised as the individual projects they are related to, which hinders standardisation in collaboration approach or product solution (Gjaltema, 2013). Therefore, the risks associated with the implementation of innovative solutions are relatively high, as supplier involvement after the realisation of the project is generally limited to a series of operational guarantees. On the other hand, none of the individual stakeholders collaborating in the construction process has enough leverage to demand substantial changes, in terms of practices and methods, from the other parties involved in the project. A possible exception to this would be the client, who could decide to maintain active involvement in the process as a decision-maker, but whose technical knowledge would generally be insufficient to demand significant structural changes. A shift towards a more active participation from clients and investors has been recently recognised. Real estate developers and managers such as Delta Development Group (Scott, 2014), and banking institutions such as ABN AMRO (ABN AMRO, 2014), are taking steps to improve the long-term health and sustainability of their projects and investments.

B. The small scale of supply companies- Façade suppliers and producers, worldwide, are in general relatively small companies (Cleton, 2014). The typical project portfolio of one of these producers could comprise between 10 and 20 projects, of varying sizes, at any given time. This means that a problem with product-delivery or guarantees in any given project can have a substantial negative

effect on the overall yearly performance of the company (and can have devastating consequences when accentuated by times of financial crises). This currently results in a façade industry that is overly cautious when it comes to implementing new technologies with a limited testing history. Instead, systems with which suppliers and contractors are familiar are chosen, and which have been proven consistently over time, even if these systems are below the state-of-the-art in terms of energy efficiency or other performance criteria. Consequently, the small scale hinders innovation, as SME suppliers cannot often afford to deviate from traditional solutions, or are prevented from doing so by market forces or decision-makers further up the value chain.

On the positive side, a small project portfolio means that SME suppliers are likely to be interested in implementing new business models, which extend their involvement in projects and ensure a long-term, steady source of revenue. This is in contrast to a product-delivery-based business structure, which forces them to constantly look for new clients and projects in order to secure a highly volatile cash-flow.

2.2 THE TECHNOLOGICAL INNOVATION MECHANISM

Next to the structural disablers that the construction industry brings from a business and supply perspective, there are technological obstacles that affect the market-integration of innovative products: A) The rate of effective technology implementation and B) Risks and uncertainties for the client.

A. The rate of effective technology implementation - The rate at which technological innovation can occur within a system is, necessarily, closely tied to the length of its (effective) implementation cycle, also known as its "vital life" (Arthur D. Little, 1981). By an effective implementation cycle we mean the time it will take between the creation of the first working prototype of a technological product, and the moment in which this product reaches the mature economy of scale, in production, which would facilitate its mass-market application. This rate is also tied to the expected service-life of the previous generation of an equivalent product, as few users will replace a system before it is technically (or in some cases socially) required. For example, Smartphone suppliers are able to make modifications to their platforms at a rate of one or even two new releases per year, because the market absorption and expected service-life of these units is, on average, 18 to 24 months. In this specific case, replacement rarely comes as a technical obligation, but is generally due to trends, marketing, and other social behaviour. In the case of façades and façade-integrated components, service-life is generally expected to fall within the range of 20, 30, or even 40 years. If we consider each product generation to be a mass-market testing prototype, it is easy to see why mobile phones have exponentially increased their involvement in our everyday life over the last 10 or 15 years, by radically changing their functionality, while façades today look quite similar to how they did 80 or 100 years ago, even though their performance and functionality have vastly improved.

New methods for product development and implementation are required, closer to those of the automotive and electronics industries, if we expect to shorten the rate at which upcoming technologies are launched into the market, tested, upgraded, improved, and replaced. Since façades are massive assemblies, hardly comparable to an automobile or a smartphone in terms of material use and replaceability, a possible approach would be to fragment the façade assembly into smaller, more manageable pieces, which can be constantly and individually reassessed with the introduction of new, more effective technologies.

B. Risks and uncertainties to the client - From the client's perspective, the decision to invest in energy-efficient systems also carries a significant risk. When we consider current occupation trends, especially in the case of residential real estate, we see that the average time a building owner will live in a single property is around 7 years (Gondrie, 2015). This is considerably shorter than the average time required for the return on investment of an energy-saving system. For example: photovoltaic (PV) solar panels are calculated to reach socket parity when the return on investment is equal to or higher than 5%, depending on the system's efficiency and the rate of inflation of energy prices (Bazilian et al., 2013). It is also a risk choosing the right moment to make a capital investment on sustainable technologies. Going back to the example of PV panels: the cost of a PV installation per Watt output has dropped by an average of 21% per year over the last 30 years (Mayer, Simon, Philipps, Schlegl, & Senkpiel, 2015). This means the capital investment required to buy such systems before they reach maturity - or mass-production scale - could negatively offset the return on investment of the system from energy savings due to a faster relative depreciation.

3 SOLUTIONS TO TRANSFORM THE CONSTRUCTION PROCESS

Innovation in building technologies, and especially energy-saving systems, has been accelerating at an unprecedented rate. Residential Zero-Energy renovations, which until recently represented an expensive, experimental concept, can now be realised for a relatively small additional investment of between 20% and 25% (Azcarate-Aguerre et al., 2017). However, as we have discussed before, the market-wide implementation of these systems, whether in new construction or in deep renovations, is significantly slowed by organisational and information-exchange bottlenecks in the construction industry.

This tendency can be counteracted through innovative business models that consider the accelerating rate of innovation in the supply industry, and reconciles it with the long-term financial commitment these systems represent for real estate demand interests. New products, released at shortening intervals, cannot be integrated into the market through traditional supply mechanisms. Innovative products and services demand innovative business practices and a deep industrial reorganisation (Van Nederveen & Gielingh, 2009; Vrijhoef, 2011).

Design, Build, Finance, Maintain, and Operate (DBFMO) contracts are a promising step in the direction of re-assigning long-term decision-making powers to a party (in this case a general contractor backed by a multidisciplinary consortium) with sufficient technical understanding of the construction and operation process (Straub, Prins, & Hansen, 2012). In such contracts, the centralised contractor in charge of developing and managing the building over a 40 or 50 year contract period, would have the level of responsibility and control needed to demand deep structural changes from product and service suppliers. However, as we will discuss further, DBFMO contracts are only partly successful as a Circular Economy implementation mechanism.

3.1 PRODUCT-SERVICE SYSTEMS AS AN INDUSTRY-TRANSFORMING STRATEGY - THE BUSINESS AND SUPPLY SOLUTION

Product-Service Systems are a Business-to-Consumer (B2C) strategic model that fits within the frame of a Circular Economy structure. A PSS business model replaces a traditional purchasing scheme, in which a supplier transfers ownership and responsibility of an asset to a buyer,

maintaining only limited liabilities over it in the form of technical guarantees. From a PSS perspective, the product on its own does not hold the final value, but is merely a mechanism through which a service can be delivered to a client (Baines & Lightfoot, 2013). To put this into an example involving PV cells: a traditional purchasing method would have a client buy the PV cells from a manufacturer, through a one-time cash payment or through a financial lease. The client would then own the panels, in many cases pay an additional fee for any required maintenance, suffer the technology's capital depreciation, and deal with the product's end-of-service scenario. In exchange for this he would generally get a return-on-investment from the energy savings in his property's operating costs. In a PSS model, on the other hand, the physical PV panels are not the item being sold, but are instead combined with the continual service delivered by those panels - through a long-term contract with the client or end-user - and charged relatively to their actual performance. In such a scenario, the client would not pay for (nor ever legally own) the PV panels, but would instead pay a fixed monthly or yearly amount based on the effective operation of the system, or even a variable amount related to the system's output (eg. Euro per Watts generated in a given month). The client is therefore paying **not for the materials** embedded in the PV panels, **but for the performance** provided by these to produce passive energy through the building's envelope. Product-Service Systems act, therefore, as a dematerialisation strategy. They remove financial incentives from the sale of physical products, and force manufacturers and service providers to optimise their service-delivery by minimising their use of material and human resources (Baines & Lightfoot, 2013).

From an industry perspective, this offers a number of advantages and a huge field for the development of new business structures to organise and manage a long-term, ongoing relation between suppliers of technologies (Original Equipment Manufacturers - OEMs), contractors in charge of delivering product-service packages, building owners, and end-users. In fact, PSS thinking is already being applied for individual components with an external interface with the building (meaning they are not embedded into the construction, nor interconnected with other components, and can therefore be installed/uninstalled with a relatively small effort). An example of this is the combination of products and financial/technical services offered by photovoltaic-leasing companies in the United States and the Netherlands (Liu, Eric, Tyner, & Pekny, 2014).

A more ambitious approach to PSS implementation would not only deal with the way in which technological systems and financial/legal contracts are packaged and sold to the end user. An integral PSS approach would completely redefine the way in which systems are designed to interact with each other by, for example, increasing standardisation and reducing compatibility issues. It would also restructure the supply chain in terms of contractual obligations. OEM suppliers would hold a long-term contract with the general contractor, who is, in turn, contracted in the long-term to deliver an optimal performance to the client. Lastly, it would promote a new form of design which facilitates replacement, upgrade, and reprocessing of obsolete components within a larger system, while guaranteeing that removed parts can be easily reused or recycled for new purposes in an expanding second hand market.

3.2 INTEGRATED FAÇADES - THE TECHNOLOGICAL SOLUTION

Integrated Façades are complex building assemblies in which a large part of the building's service and climate-control systems are contained within the modular construct of the building's envelope. Integrated façade principles can be found in both curtain wall designs, as well as in self-standing modular window boxes (Klein, 2013). In most cases, a wide frame surrounding the glass façade surface will contain diverse technical systems such as: Cooling and heating, ventilation, heat-exchange, shading, energy generation and/or storage, media projection, electric and water supply, and performance-monitoring sensors.

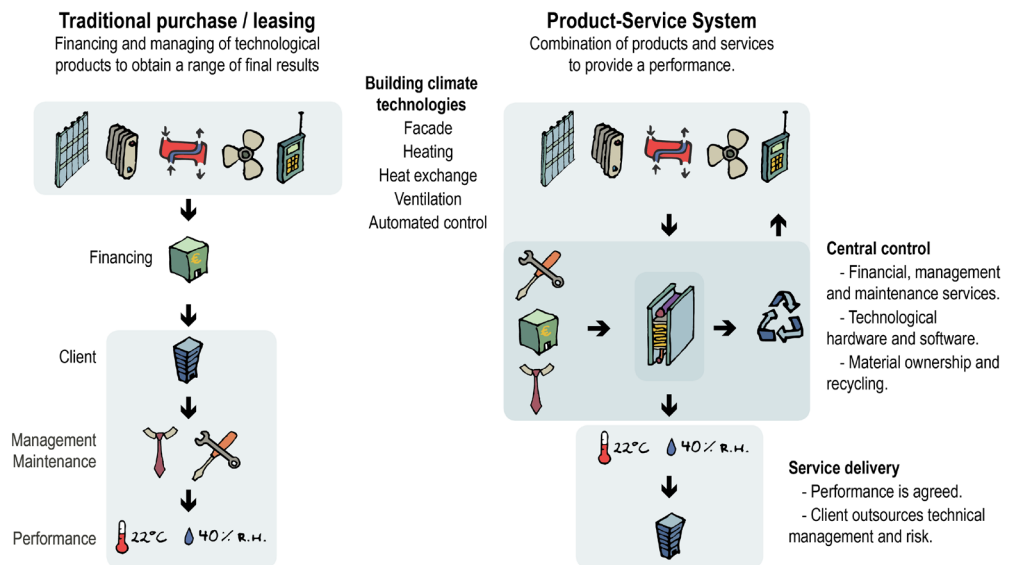


FIG. 29 Schematic shift from a traditional Product-System to a circular Product-Service System for integrated façades.

For certain building typologies, such as cell offices, integrated façade systems can virtually eliminate the need for centralised building services which results, from a PSS perspective, in two major advantages: 1) It combines two of the four basic building elements (Structure, Envelope, Building Services, and Building Infill) into one; and 2) It facilitates the distributed functioning of envelope-integrated services according to room occupation trends, thereby avoiding the negative centralised-system effect in which large sections of the building are conditioned even when not in use.

Combining the Envelope and Building Services elements of a construction is a logical step, when we consider how closely related they are in terms of expected service-lives. While the structure of a building is generally expected to last for 50, 100, or 200 years and the interior finishes and mobiliary can be changed as often as every 5 or 10 years, building services generally provide a technical service-life within the range of 15 to 20 years. Envelopes are expected to perform for between 20 and 40 years. Combining these systems on the outside of the building can facilitate and coordinate renovation and system-replacement processes in terms of both logistics and use of materials.

Concentrating climate-control mechanisms in the façade also means the envelope will play a more determinant role than ever before in the efficient climatic and energy performance of the building, which can be an advantage when defining utilities-inclusive contracts. A Product-Service System approach to the design, installation, and operation of integrated façade modules (Fig. 2) would allow a service-provider to estimate, within a reasonable range, the impact of his modular products on a specific building's indoor climate and energy consumption, therefore allowing him to offer a long-term, performance-based contract, as opposed to a single outright-purchase option. It is important to note that the effect of façade and building services on climatic and energetic performance can vary according to diverse building types. It is, however, beyond the scope of this paper to analyse the extent to which a façade service provider can guarantee a determined indoor comfort level.

3.3 THE POTENTIAL OF PSS FOR THE IMPLEMENTATION OF A CIRCULAR ECONOMY

The potential of Product-Service Systems for the implementation of a Circular Economy model lies in the correct distribution of ownership, responsibilities, and interests throughout the supply chain (Joustra, de Jong, & Engelaer, 2013). Under the current business structure, producers and installers of technological systems and building components are only tied to their products by a legal mechanism based on guarantees and liabilities. Such a system “punishes” the under-performance of a product, instead of “rewarding” its over-performance (Fig. 3).

A linear supply chain (the one currently dominating the Architecture, Engineering, and Construction industry) will have each step of the supply mechanism surrendering ownership of the physical products to the next, in exchange for a certain degree of technical guarantees. All systems are ultimately transferred to the client (by definition, in most cases, the party with the most limited technical knowledge), who then has to hire a team of facility management experts to extract the best possible performance out of these systems. Long-term efficiency, apart from major faults which would have to be covered by guarantees, are not in the interest of suppliers and manufacturers, as they no longer maintain financial ties or incentives to this performance.

End-of-Service scenarios are also negatively affected by this business structure; the client, and owner of the materials contained in the building, will frequently surrender ownership of these materials to the company in charge of demolition as a form of payment. The materials will then be extracted with varying degrees of effectiveness, and the output sold in the global market. Processing and logistic costs are high, as components are not originally designed for disassembly, making their separation process difficult and inefficient. Their sale on a global market reduces the chances that these materials will be re-used locally, thus increasing transportation expenses and related CO2 emissions.

An intermediate business model would have a driving stakeholder - on the supplier side - being responsible for the construction and operation of the building over a determined period of time. In DBFMO contracts, for example, the general contractor in charge of the project's 30- to 50-year service-life will retain responsibility over the effective performance of the building and its systems, he will then rent the building to the client for a fixed yearly fee. DBFMO contracts do not, however, strictly follow the principles of PSS thinking, and are instead a form of extended financial lease. The contractor is effectively the constant manager of the building, and is in charge of the financing and maintenance of all components, but these contracts often do not include utility costs (meaning the contractor cannot draw direct incentives from the energy-efficiency of the building, and instead is only penalised if the performance is below a specified benchmark) and they do not specify a strategy for dealing with the building's materials at the end of the contracted period. At that point in time the client might simply become a traditional owner/manager of the building, or it might be sold in the market, or rented out in a new lease contract. The end-of-service scenario for the construction materials is therefore equally uncertain, as demolition and recycling are generally not included as part of the original planning and contracting process.

A true PSS-oriented business model will have all stakeholders tied, materially and financially, to the optimum performance of the building throughout its service life, including end-of-service material extraction and reuse. This is however, not in the form of penalties for below-expected performance, as in the case of an operating lease, but in the form of incentives for above-expected results. A PSS method for the installation of integrated façades would include utility costs from climate control.

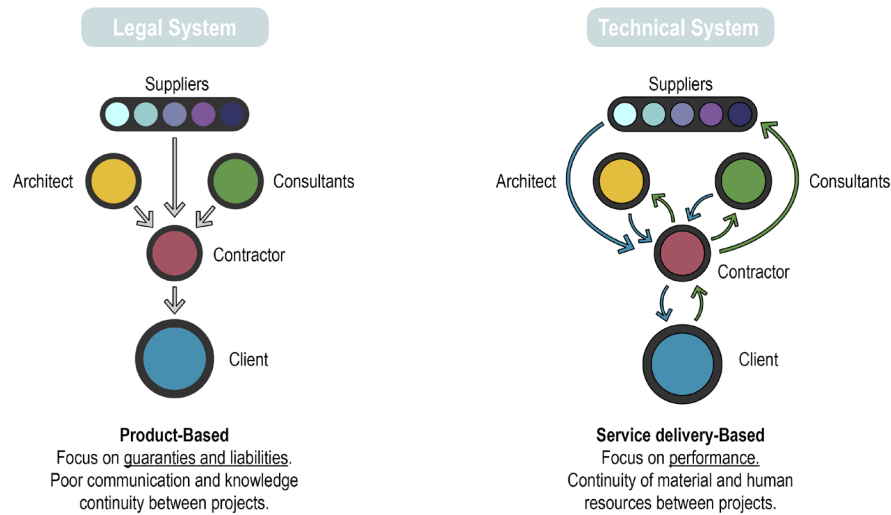


FIG. 30 Schematic linear vs. circular supply-chain structure, from "punishment" to "reward".

The Product-Service System would use the integrated façade modules as a product to deliver a final indoor comfort and energy performance as a service. This means PSS façades can become a method of Energy Performance Contracting (EPC) in which the cost of a façade renovation, through leased components, can be partially or totally repaid through the savings resultant from their increased energy efficiency. The continuous nature of the Service-Provider's role throughout the components' service lives, and the fact that an improved energy performance will result in direct profit increase, means it will be in his primary interest to maintain an optimal overall building performance through the use of updated technologies.

4 DISCUSSION AND CONCLUSION

In theory, integrated façades as Product-Service Systems have the potential to permanently bridge the technical, financial, and legal knowledge gap between producers of building technologies, builders, managers, and clients. By treating each building project as an ongoing service (which may last decades or even centuries) instead of as a delivered product, a PSS can not only integrate a Circular Economy mindset into the construction industry, but also set up the business mechanisms that will ensure all parties in a project are committed, in the long term, to a single goal: the best possible functional performance of a building with the most effective, minimum use of resources. However, this transition requires changes in the innovation process, which starts with persuading stakeholders to explore the advantages, and weigh these advantages against the uncertainties and risks. Conclusions about the required PSS characteristics and conditions – the PPS brief – are summarised below.

The following section presents our arguments, from a multi-stakeholder perspective, on how this transition towards a service-oriented industry can be achieved (section 4.1), and why this transition is in the interest of the principal parties involved (section 4.2). It then discusses the state of research, and proposes a series of future steps necessary to bring this concept closer to its practical realisation (section 4.3).

4.1 CHANGING ROLES IN THE INNOVATION PROCESS

Successful radical innovation requires a major crisis or market opportunity. If the construction industry wants to develop into a market with more innovative capabilities, the innovation process has to change as well (Bers, Dismukes, Miller, & Dubrovensky, 2009; Vrijhoef, 2011; Joustra, de Jong, & Engelaer, 2013).

Such an industry-wide shift will not be reached without a fair amount of restructuring and collateral damage. The financial demands and long-term stability required by a long-term ongoing project could, ultimately, be unfeasible to many smaller players in the supply chain (such as subcontractors or system providers), who might have to expand and merge their businesses, or sacrifice profit under pressure from larger players further up the supply chain. General contractors will have to plan their future operations based on how many buildings they can afford to manage at any given time, while ensuring they maintain a diverse enough portfolio, instead of the current model based on delivery dates and a constant search for new contracts. This represents a major shift in the traditional business practices of such companies. The cost and risk of this transition could have a negative effect on a number of organisations and stakeholders, but could be rewarded with a greater financial stability and improved solidity to face economic fluctuations or crises.

A. The financial sector needs to stimulate and support changes in supply and demand business models by applying new financing mechanisms. Recent studies by large banks (ING Economics Department, 2013; ABN AMRO, 2014) already show that they are exploring more innovative technical/financial packages to support new business models. The road for this has been set by relatively simpler contracting methods employed by other industries, with mobile phones and cars being among the most common. Such industries have certain advantages in this regard such as, to name but a few: a longer service-based contracting track-record, higher product-service standardisation, a clearer demarcation between client and supplier roles, and standard contract termination terms. All of these contribute to lower uncertainty and hence lower risk premiums.

The construction industry, meanwhile, is entering an exploratory phase, in which such contracts and multi-stakeholder relations are being tested in customised scenarios, while standard contracts and risk management structures are still to be developed. The 2008 financial crisis will provide a useful background for this development, as large financial institutions have been forced to change their strategy and (further) diversify their investment portfolios, thereby providing leverage against the uncertainties of increasingly fluctuating economic cycles. Financial regulation on real estate investments, which is currently based on preserving overall property value through clear ownership structures, must adapt to understand and include models of collaborative service-focused ownership. Non-regulated, or improperly regulated, investment models could have a negative effect on the sustainability of the building stock if they lead to the creation of complex, deceptive, high-risk financial products such as those which triggered the 2008 global financial crisis.

B. The architectural practice needs to re-assess the value given to unique, irregular forms and highly customized assemblies, and consider decisions based on a modular interaction between high-performance building components. This does not mean architectural design should become a secondary priority, completely restricted by the functional requirements of standardised building technologies. However, a leasable system would rely on a certain degree of modularity and interchangeability as a way of increasing the residual value of components, which would in turn have an effect in the conceptualisation and design development processes of architects and designers.

C. Building owners – and other demand-side stakeholders – will need to explore the added value of alternative business models and (re)evaluate the traditional concept of ownership. In fact, this exploration has already been taken place in many organisations, under the influence of agreements to reduce the carbon footprint and ambitions to be frontrunners in innovation. Examples can be found at universities, hospitals, and financial institutions with large building portfolios (Den Heijer & Teeuw, 2010; Joustra, de Jong, & Engelaer, 2013; ING Economics Department, 2013; ABN AMRO, 2014).

Ongoing research has found that tools to accurately compare Total Cost of Ownership for diverse investment options still need to be further developed. This is particularly evident in the case of accurate methodologies for evaluating direct and indirect operational costs in existing buildings, information which is crucial in determining the economic attractiveness of a traditional or service-based façade renovation project.

D. New generations of decision makers have seen great advances in the concept of use and access above the concept of ownership (Rifkin, 2000). Innumerable modern assets, such as printers, phones, cars, and real estate, are now frequently leased, rented, or shared. This represents a significant cultural deviation from a traditional tendency to own a wide range of physical assets. Internet-based applications have facilitated the dissemination of “sharing-economy” models in which people within a certain region can share products or services upon demand without the need for intermediaries (apart from the internet-based application itself). These socio-cultural changes create a positive atmosphere for the growth of more complex systems of performance-based Business-to-Business (B2B) contracting in which physical components constitute a means and not an end.

The broader social and economic consequences of such disruptive models are still, however, not fully understood. A shift towards Product-Service Systems could also entail a concentration of resource ownership in the hands of companies, which could exacerbate economic polarisation trends contributing to growing wealth gaps, both locally and globally. Such systemic consequences are difficult to model and predict, and must therefore be taken into account and monitored throughout the development of circular business models such as the one presented in this thesis.

4.2 ADDED VALUE OF PSS FOR STAKEHOLDERS

An additional complexity built into the construction industry is the highly significant impact this sector has on a wide range of direct and indirect stakeholders. While a poorly functioning household item will only create a problem for the user and can most likely be returned to the manufacturer for reprocessing without any major effort, a building has a permanent presence within its context over one or more human generations. This means that the stakeholders in a building are not only the supply and demand parties directly involved in its construction and operation, but also its end users, city inhabitants, regulatory bodies, infrastructure providers, and countless others. The adoption of a Circular Economy process, in the form of PSS building components, offers considerable incentives to most of the parties involved (Fig. 4), especially in times of economic uncertainty when preconceptions about our economic and industrial activities should be revised. The wider groups affected by processes in the industry are listed below:

A. Demand-side stakeholders could initially benefit the most, especially now that real estate managers are more likely to focus on Total Costs of Ownership, and not only initial investment. Rising energy prices, social trends that value the aesthetics of a “brand-new” and “high-tech” appearance, and accelerating technological innovation create a substantial economic pressure, which causes buildings to depreciate at an ever-faster rate. Real estate owners and managers are

more aware than ever of the value of maintaining their building portfolio in optimal conditions. Dealing with this depreciation, however, requires deep technical understanding of the systems operating within the building (more so as buildings become more complex and filled with highly-specific technologies). By outsourcing the entire life cycle of diverse building components to technical experts who have a clear understanding of them, clients can avoid the struggle and financial risks associated with managing these systems themselves. A PSS approach would provide the following advantages according to the 4-value performance criteria identified at the start of this paper (Fig. 1):

Sustainable/Energy - As mentioned thoroughly in this article: Sustainable, energy-performative technologies are being released into the market at accelerating rates. The strategic and financial value these technologies offer to a client institution is closely related to the use of state-of-the-art systems. Such systems can be made available and replaced (efficiently) within shorter intervals through leasing mechanisms that guarantee operational consistency and material conservation. Risks presented by lower than expected actual energy-savings, for example caused by the documented rebound effect (Guerra Santin, 2013), need to be taken into account, and might lead to additional monitoring and/or financial costs.

Functional - Rapidly shifting Real Estate trends demand increasing levels of flexibility in a building's architectural programme, occupancy, aesthetic design, and technical services. A service-based supply business model would significantly increase the capacity of real estate managers to respond to these changes by modifying the performance, appearance, and specifications of their building portfolio, without being weighed down by long-term investment cycles.

Strategic - The European market for commercial real estate is currently suffering from a high vacancy rate. The excessive supply of commercial floor space in certain regions forces building owners to think about additional values, which they can offer to potential clients in order to distinguish themselves from their competitors. Leasable façade systems would allow more frequent renovations and a wider functional flexibility (as stated above), which would in turn result in more attractive properties with more frequent maintenance schedules and a higher energetic performance and user comfort.

Financial - In many cases, real estate ownership and management is not the primary business activity of the client institution. Leasable products provide more equally distributed, constant cash-flows, making real estate investments more predictable and eliminating the current peaks in capital flow over a building's service life: construction, major maintenance/renovation works, and deconstruction. Outsourcing technically-demanding services, while eliminating financial peaks, would allow clients to focus resources on their primary business activities.

B. Supply-side stakeholders, on the other hand, could exploit entirely new areas of business development. As we see with other manufacturing industries, operation and financial services are among the most profitable activities a company can engage in. Combining building components (products) with a combination of technical and financial services would thus expand the range of activities from which construction companies currently derive their revenues. Not only would it expand it but, as mentioned earlier, it would spread these revenues over a constant, steady income flow, stabilising their long-term finances and reducing their vulnerability in times of economic turmoil. This is especially relevant to the sector because, as we know, the construction industry is generally among the first and hardest hit by financial crises due to their high dependency on a small number of large, short-term projects (Cleton, 2014).

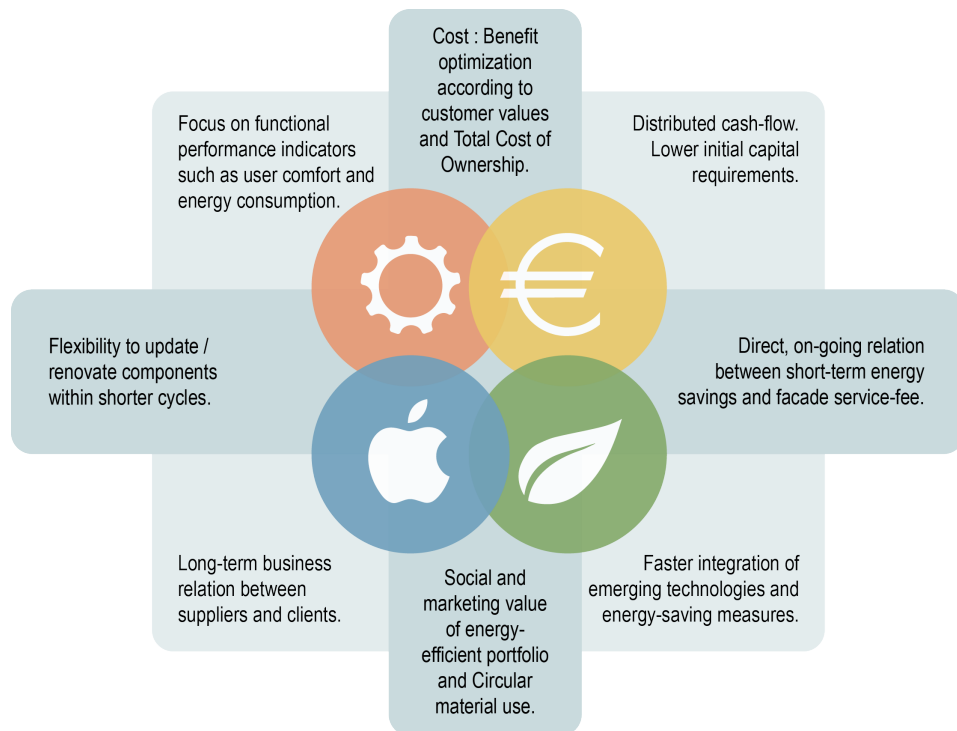


FIG. 31 Benefit overview of a PSS façade concept according to Den Heijer's 4-value criteria.

The focus on product's performance could meanwhile incentivise product innovation by shifting the focus to entire Life-Cycle engineering. Design decisions could, for example, justify higher material content or quality in exchange for longer service-lives, or lower maintenance costs. Additional investment on disassembly mechanisms could be financially justified if they lead to component or material preservation within closer economic loops of reuse, repair, and remanufacturing. This replaces traditional recycling processes which often entail the down-cycling of valuable and critical materials due to unfeasible separation costs.

C. Regulatory bodies and society as a whole would benefit from the more efficient use of material and financial resources resulting from keeping complex technical systems in the hands of industry experts. A circular business model, in which all parties involved in the project have a permanent interest in the correct performance of the building, would naturally lead to a more effective use of energy and raw materials (as waste of either one of them would negatively affect their business' profitability), while guaranteeing the best possible end-of-service management of all systems. Constantly involved supply-side partners would have a technical platform, and the direct incentives, to integrate new technologies more quickly into the market, making transition happen at a faster rate throughout the construction industry. Demand-side clients with more regular cash flows dedicated to covering real-estate costs would have more stability to focus on their primary processes and business objectives.

4.3 FOLLOWING STEPS

This paper has established the general conceptual frame of a Product-Service System for the delivery of Façades-as-a-Service. It has set the basic parameters to be taken into account when designing a PSS-based business model, and formulated a value proposition from the diverse perspectives within the supply and demand sides of the construction industry. As mentioned before, many of the concepts

presented in this article have been extrapolated from better documented examples belonging to other manufacturing industries which have undergone a transition towards servitisation. In order to better understand the differences of applying such models in the construction sector, our team is currently in the process of developing a pilot project and testing environment with the active participation of industry representatives from the identified stakeholder groups.

Barriers and opportunities can already be identified in the transition towards Façades-as-a-Service, and need to be further explored. One possible drawback of this system would come from the complexities of user behaviour. As seen in numerous studies, energy-based renovations frequently create a “rebound” effect, in which “Occupant behaviour has a significant effect on energy consumption, given the higher temperature settings in dwellings with insulation, mechanical ventilation and more efficient temperature control” (Guerra Santin, 2013). A possible solution for this problem would be to include a maximum-energy-use clause in the contract, specifying the range of energy consumption guaranteed by the service provider, above which the difference will be charged to the user. Another solution could be the implementation of complex monitoring systems which differentiate the building’s base consumption from additional losses due to negative user behaviour.

More in-depth knowledge is also needed regarding the current process for decision-making, procurement, and contracting, which governs the building practice during the development stages. Further research will elaborate upon the value proposition offered by a PSS business model according to the project’s target market, and offer alternatives as to which stakeholders within this supply chain could drive the transition to this new form of thinking. A strong focus on the demand and regulatory side will be crucial to determining further conclusions, as we believe the re-organisation of the supply industry would not be effective on its own. Instead, clients and governing bodies must clearly recognise the value these ideas hold to support their activities and interests, and be ready to undertake the structural changes necessary for their implementation.

A clearer picture of the needs and processes undertaken by owners and operators of real estate could lead to higher definition in the applicability of a PSS-based integrated façade, from a business perspective. Further research must elaborate on the conditions and incentives (established in Section 4 of this paper) that are required for this model to be applicable in practice. A combination of schematic technical and business prototypes must be used to develop and analyse a real-life pilot project. The objectives of this exercise must be to bring into the discussion many of the diverse stakeholders analysed, and discuss the value proposition of our model through tangible examples based on a real building case. This will facilitate a practical evaluation of the pros and cons of Façades-as-a-Service, assessed through a realistic pilot project.

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References

- ABN AMRO (2014). *Circular construction – the foundation under a renewed sector*. Amsterdam: Circle Economy for ABN AMRO, December 2014.
- Azcarate Aguerre, J., Konstantinou, T., Klein, T., Guerra Santin, O., Steensma, S., & Silvester, S. (2017). Investigating the business case for a zero-energy refurbishment of residential buildings by applying a pre-fabricated façade module. *eccee 2017 Summer Study on Energy Efficiency*. pp. 1113-1122[3]
- Baines, T., & Lightfoot, H. (2013). *Made to serve: how manufacturers can compete through servitization and product service systems*. Chichester, West Sussex, United Kingdom: Wiley.
- Banfi, S., Farsi, M., Filippini, M., & Jakob, M. (2008). Willingness to pay for energy-saving measures in residential buildings. *Energy Economics*, 30(2), 503-516.
- Bazilian, M., Onyeji, I., Liebreich, M. et al. (2013). Re-considering the economics of photovoltaic power. *Renewable Energy*.
- Bers, J. A., Dismukes, J. R., Miller, L. K., & Dubrovensky, A. (2009). Accelerated radical innovation: Theory and application. *Technological Forecasting and Social Change*, 76(1), 165-177. doi: DOI 10.1016/j.techfore.2008.08.013
- Chao-Duvis, M.A.B., Koning, A.Z.R., & Ubink, A.M. (2013). *A practical guide to Dutch building contracting*. 's-Gravenhage: Instituut voor Bouwrecht.
- Cleton, I. (2015). *Creating value with sustainability*. PD Eng. Dissertation, Stan Ackermans Institute, Eindhoven 2015.
- C2C Bizz (2013). Guided Choices Towards a Circular Business Model, INTERREG IV B Report of C2C Bizz consortium (authors: Douwe Jan Joustra, Egbert de Jong, Frits Engelaer) for project Samenwerkingsverband Regio Eindhoven (SRE), November 2013.
- Den Heijer, Alexandra (2013). Assessing façade value – how clients make business cases in changing real estate markets. *Journal of Façade Design and Engineering* (1) pp. 3–16, December, 2013.
- Den Heijer, Alexandra (2011). *Managing the university campus – Information to support real estate decisions*. Delft: Eburon Academic Publishers, March 2011.
- Den Heijer, Alexandra and Peter Teeuw (2011). Sustainable visions for the campus of the future. *MISBE 2011, Management and Innovation for a Sustainable Built Environment*. 20-23 June 2011, Amsterdam, The Netherlands.
- Gjaltema, G.M., Vrijhoef, R. (2013). Experimental Design Strategy as Part of an Innovative Construction Industry. *7th Nordic Conference on Construction Economics and Organization* (2013), 227-238.
- Gondrie, N. (2015). *Renovation, Leasing a Prefab Renovation in the Netherlands*. MSc thesis TU Delft, Delft: Faculty of Architecture and the Built Environment, January 2015.
- Guerra Santin, O. (2013). Occupant behaviour in energy efficient dwellings: evidence of a rebound effect. *Journal of Housing and the Built Environment*, 28(2), 311-327. doi: 10.1007/s10901-012-9297-2
- ING Economics Department (2015). Rethinking finance in a circular economy: Financial implications of circular business models. Amsterdam: ING Bank, May 2015.
- Klein, T. (2013). *Integral Façade Construction - towards a new product architecture for curtain walls*. Dissertation, Delft Technical University, Delft 2013.
- Little, A. D. (1981). The strategic management of technology.
- Liu, X., Eric, G. O., Tyner, W. E., & Pekny, J. F. (2014). Purchasing vs. leasing: A benefit-cost analysis of residential solar PV panel use in California. *Renewable Energy*, 66, 770-774.
- Marszal, A. J., & Heiselberg, P. (2011). Life cycle cost analysis of a multi-storey residential net zero energy building in Denmark. *Energy*, 36(9), 5600-5609.
- Mayer, J. N., Simon, P., Philipps, N. S. H., Schlegl, T., and Senkpiel, C. (2015). Current and future cost of photovoltaics. *Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems* (Fraunhofer ISE, Study on behalf of Agora Energiewende, Freiburg, 2015).
- Rifkin, J. (2000). The age of access: The new culture of hypercapitalism. *Where All of Life is a Paid-For Experience*. New York: Tarcher.
- Scott, L. (2014). Park 20|20, Amsterdam: Born to Be Recycled. Urban Land (article based on interview with Coert Zachariasse, Delta Development Group), May 5, 2015. Retrieved from <http://urbanland.uli.org/sustainability/park-2020-amsterdam-born-recycled/>
- Straub, A., Prins, M., & Hansen, R. (2012). Innovative solutions in Dutch DBFMO projects. *Architecture Science*
- Van Nederveen S. and W. Gielingh (2009). Modelling the life-cycle of sustainable, living buildings. *Journal of Information Technology in Construction (ITcon - Special Issue Building Information Modeling Applications, Challenges and Future Directions)*. Vol. 14, pg. 674-691.
- Vrijhoef, Ruben (2011). *Supply chain integration in the building industry: The emergence of integrated and repetitive strategies in a fragmented and project-driven industry*. PhD thesis, Delft: IOS Press, November 2011.
- Womack, J. P., Jones, D. T., Roos, D. (1990). *The machine that changed the world: based on the Massachusetts Institute of Technology 5-million dollar 5-year study on the future of the automobile*. New York: Rawson Associates.