Designing Product-Service Systems: A Review Towards A Unified Approach

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Abstract

The study addresses the design of Product-Service Systems (PSSs) as a means of replacing conventional product sales with comprehensive solutions. The shift towards PSSs however is problematic given the challenges of integrating products and services. Moreover, views regarding the design of PSSs are diverse and dissimilar. The research discusses the importance of PSSs and analyses the current approaches regarding design methods and design processes in terms of product-service integration. The analysis led to the proposal of a unified, generic design process, built on the Design Science approach where the existing differences in the literature are converged towards a holistic model. The model consists of four stages each including its intricate activities. The stages are built following a structure similar to product design, exposing the key activities to carry out as well as the tools to realize them.

Keywords

functional product, integrated product-service offerings, product-service systems, sustainable design, product-service system design.

1.Introduction

With environmental concerns at their limit, modern industries are opting towards Product-Service Systems (PSSs) as a means of combining economic prosperity and customer satisfaction with improved ecological sustainability. These systems are based on providing the customer with holistic solutions based on functional results instead of traditional product sales. PSSs combine products and services in order to achieve what the stand-alone artefact cannot do or even realize it in a better way. Additionally such approaches enable the manufacturer to thrive for innovative solutions to equally meet customer and environmental requirements (Mont, 2002; Beuren et al., 2013).

The customer, in other terms the receiver of the PSS, obtains a result customized to his personal needs through the incorporated services while the manufacturer, the PSS provider, gains the receiver's trust and loyalty.

From an environmental perspective, the tangible artefacts are better managed, as the manufacturer would have more control and use it in a better way than the customer. This leads to an optimized use of resources and easier implementation of end-of-life activities such as recycling and re-use, allowing the manufacturing cycle to adopt a cradle-to-cradle outline where the end products of one process can be used as the inputs of another (Tran and Park, 2015). Many authors have provided different definitions to PSSs (Table I). Nevertheless, three main types of integration are defined:

1. Product-Oriented (PO): the ownership of the product is transferred from the PSS provider to the PSS receiver in addition to supplementary services that increase the overall value of the artefact (i.e. warranty, maintenance, training).
2. Use-Oriented (UO): the ownership of the product remains with the manufacturer and the customer is charged a fee for the usage or availability of the product (i.e. sharing, leasing, renting).
3. Result-Oriented (RO): the provider delivers a result that answers the receiver's requirements. The second does not use the product and awaits an outcome agreed on with the provider. The provider has the largest amount of freedom to deliver the result: innovation and value maximization are most prevailing in these types of systems (Tukker, 2004; Ostaeyen, 2014).

Table 1. PSS definitions

Author(s)	PSS definition
Goedkoop et al., 1999	A PSS is a marketable set of products and services capable of jointly fulfilling a user's need.
Manzini and Vezzoli, 2002	A PSS can be defined as the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services, which are jointly capable of fulfilling specific client demands.
Brandstotter et al., 2003	A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally a product service system tries to reach the goals of sustainable development.
Sakao and Lindahl, 2009	PSSs is a concept that integrates products and services in one scope for planning, development and delivery, thus for the whole life cycle.
Tischner et al., 2009	System of products and services (and infrastructure), to jointly cope with the needs and demands of customers in a more efficient way with better value for both businesses and customers, compared to only offering products.
Meier et al., 2010	PSS: system combining physical products and services that have been integrated and optimized from a life cycle perspective in relation to customer value
Schroedl and Turowski, 2011	Offerings that provide tangible goods as well as services and intangible assets in an integrated manner.
Zhang and Haapala, 2011	A PSS is an integrated system of people, products, and services engaged in the pursuit of life cycle economic, social and environmental benefits while fulfilling customer needs through added value.
Ostaeyen, 2014	A PSS is an integrated offering of products and services with a revenue mechanism that is based on selling availability, usage or performance.

Throughout its expansion, many studies regarding PSSs have emerged, yet the integration and design processes are described as a high-level design structure while the intricate steps involved in each stage of the process remain incomplete and undetailed (Baines et al., 2009; Beuren et al., 2013; Matschewsky et al., 2015; Mourtzis et al. 2016). Some processes/models focus on the designing the solution from a customer's perspective, thus prioritizing customer requirements at the expense of the product-service integration activity (Alonso-Rasgado et al., 2004; Berkovich et al., 2014; Touzi et al., 2013). Others prioritize the environmental performance of the PSS (Aurich et al. 2006, Shekar 2007; Pezzotta et al., 2012). And in other studies, the integration and the design of the products and services are highlighted as the core of the solution (Marques et al., 2013; Tran and Park, 2014).
To address these inconsistencies, the research analyses the current design approaches and processes to define the advantages and disadvantages of each. The analysis results in a convergence of the design approaches towards a unified PSS design process.
A literature review presented in Section 2 covers the existing design process models in terms of PSS design. In Section 3, the existing PSS models are analysed according to the activities involved in each, presenting the extent and limitations of the latter. The information derived from this analysis of the models leads to model a unified PSS design framework, discussed in section 4. Section 5 reflects on the results achieved and addresses future research work.

2. Literature Review

A PSS combines products and services in an integrated notion of assessing, designing, manufacturing and distribution. Customer requirements do not depend solely on product ownership: a physical product can only provide its user with pre-defined results based on previous experiences, customer feedback, expert opinions and little or limited knowledge of future demand. Integrating products and services shifts this stance towards a more customized and dynamic point of view: a PSS's supplement is providing the customer with a result customized to

his own desires and necessities, fulfilling his current requirements from one hand and adaptable to future desires and requests.
The numerous definitions in Table 1 show the rising popularity of PSSs as well as the absence of a mutual understanding of the matter (Exner et al., 2014; Lindahl et al., 2014). Correspondingly, the most dominant PSS design methods were developed in specific contexts given defined circumstances and settings (Muller, 2013). A large number of companies are seeking to develop PSS solutions. The transition to shift from product sales to PSSs however requires a robust and generic methodology that guides the manufacturer throughout the entire process to design and develop effective solutions (Baines et al., 2009; Vezzoli et al., 2015; Yoon et al., 2012). The dominant design methods in the current PSS literature points out their inability to provide comprehensive solutions (Tran and Park, 2015). A guideline is needed to support manufacturers during the design process. Additionally, most design approaches are limited to the concept development stage and do not describe a comprehensive process applicable regardless of the manufacturer and his circle (Boehm and Thomas, 2013). These design methodologies are exposed in Table 2.

Table 2. PSS design methods

Design Methodologies	Overview	References
Integrated Product and Service Design Process	The relations between the tangibility of a product and the intangibility of services provide potential for integrated design processes: hence the joint development of products and services and their interactions increases the overall value	Aurich et al., 2006; Sakao et al., 2009; Welp et al., 2008; Maussang et al., 2007; Maussang et al., 2009
Fast-Track Total Care Design	Functional performance based on integrated services and products within the development of an offering.	Alonso-Rasgado et al., 2004; Flieb and Keinaltenkamp, 2004
Service Engineering Framework	A design method that integrates a product service design modelling tool with a discrete event simulation test-bench	Duckwitzl et al., 2008; Baines et al., 2009
Service CAD	A systemic business model design methodology to increase eco-efficiency in a holistic manner	Arai and Shimomura, 2005; Komoto, 2008
Service Explorer	Utilization of service engineering to increase the product's value via services	Sakao et al., 2009; Sakao and Lindahl, 2009
Requirements Data Model	A method founded on clarifying and defining the requirement specifications by defining the structural principles of a PSS design approach.	Van Halen et al., 2005; Scholl et al., 2010; Berkovich et al., 2014
Spiral Design Process	A product-service strategy and methodology that creates revenues over the whole life cycle	Tan and McAloone, 2006; Pezzotta et al., 2012
Functional-Blueprint Design Approach	A merger of the service blueprint with product design's functional bloc diagram tool in order to convey a unified approach for PSS design	Trevisan et al., 2015
Development process of an integrated solution	Methodological tools that describes PSS development as the combination of two spaces: the problem space to generate requirements and the design space to fulfll them	Morelli, 2006

Given the design approaches shown in Table 2, the design process of a PSS was addressed. To do so, we analysed the existing models that provide a structured procedure to lead designers in PSS development. The models are

considered from a product manufacturer's standpoint. More specifically, the models concern manufacturers aiming to transition from conventional product sales to integrated product-service solutions: PSSs.
In particular, the investigation was considered from the manufacturers' perspective to obtain a viable evaluation of their shift from conventional solutions towards service-integrated offerings, in other terms PSSs. Two general categories of design models were deduced: a business model approach and a technical design model approach.

2.1 The Business Model Approach for PSSs

A business model method focuses on the internal operations of the manufacturing company: product portfolio, activities and supporting infrastructure. These operations are portrayed as building blocks which when assembled, deliver a holistic solution. The blocks are categorized intro strategies and protocols to define the revenue model, the cost structure, customer segments, distribution channels, customer relationships, the stakeholders network, the company's resources and the value proposition (Chadee and Pang, 2008; Geum et al., 2011a).
Revenue model: The revenue model consists of defining and choosing the type of definitions that will allow the manufacturer to benefit from his product-service sales. The PSS can deliver a product or service, allow the use of a commodity or deliver a functional result in any possible means and reap the benefits by concentrating on advertisements, developing customer relationships, improve its brand reputation or penetrate new market segments (McGrath, 2010).
Cost structure: To examine the cost structure and visualize the associated costs and risks, a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis is vital to outline the macro-factors related to the developer's environment. A SWOT analysis allows understanding the company's position on the market. More in detail, cost structure management is a pivotal element of the PSS's failure or success (Sundin et al., 2009). "The new logic of value creation requires new value-based pricing models, which include products and their associated services (Gronroos, 2011)". Financial and accounting practices need adaptations, since the time scale of financial flows changes considerably from an almost immediate return of capital to an extended usage period.
Customer segments: consist of identifying the potential customers of the solution, and defining and prioritizing their requirements. Understanding customer behaviour is decisive, as different customers will see PSS ideas differently. Their perception of product ownership, responsibility and availability as well as their habits and cultural habits can differ significantly (Tukker and Tischner, 2006; Lee et al., 2011).
Distribution channels: the strategies to deliver the product and the service compose the distribution channels. Strategies to consider conveying the product or service vary depending on the company as well as the type of solution being offered. Integration within the plant's walls is subject to a rigorous analysis to improve the entire delivery process. The PSS offer should be made more attractive than the stand-alone counterpart and hence the retails and sales staff require appropriate training to emphasize the advantages of a PSS (Tukker and Tischner, 2006). Additionally, distribution tactics such as direct/indirect channels for example and a supporting IT infrastructure are needed to manage provider-receiver communications (Lee et al., 2011).
Customer relationships: Retaining the customer and gaining exposure is highly related to economic incentives and customer-oriented activities i.e. advertising, consultancy and education. Standardization is a key element that strengthens the manufacturer's stance and his operational strategies in terms of managing products and services. Incorporating the customer in the value-creation process develops a vital element of a PSS: customer relationships.
The stakeholders' network: a PSS offering necessitates a complex actor/stakeholder network: suppliers, distributors etc. All the actors have to be identified to understand how each one of them contributes to the PSS in terms of value, costs and competencies. Forming networks, assigning activities, outsourcing, internal and external cooperation have to be described to establish effective value and business strategies (Van Halen et al., 2005; Lee et al., 2011).
Company resources: PSS providers require substantial resources especially in terms of the workforce and the needed infrastructure. Training and new abilities to manage customers is fundamental. A skilled workforce allows proper communication of the value offering of the system from one hand, and capturing customer requirements in a suitable manner from the other. Thorough and exact understanding of the latter, allows engineers to develop customized and personalized systems for a favourable success.
Value proposition: value is irrelevant unless delivered to its receiver. It is a combination of the resources, tasks, partners and channels that allow its delivery. In other terms, it "relates to the value provided by the integration of products and services. Examples of value are as follows: lower responsibility for the product lifecycle, guaranteed functionality (Isaksson et al., 2009), and reduced cost of manufacturing operations when the customer is another company, since the PSS provider may be responsible for services such as maintenance and repair (Alonso-Rasgado

et al., 2004). Customization can also be a value proposition, since a PSS enables the combination of product and service elements (Tukker and Tischner, 2006). Stakeholders perceive the value according to their roles, responsibilities and product experience. For example, the perception of a product value changes when it is sold or leased, as does the trade-off between incurred costs and liabilities for the customer (Fishbein et al., 2000). A particular perspective is the value of the relationship with customers during the role lifecycle of products. Finally, value also encloses a subjective dimension i.e.: trust, commitment and attraction (Barquet et al., 2013)".

2.2 The Technical Design Model Approach for PSSs

The second substantial design model focuses on the technical design of the products and services to offer.
Accordingly, this manner of designing PSSs differs depending on the type of the PSS envisioned by the manufacturer. For example, if the PSS is product-oriented, then product design is prevalent and precedes service design. In a use-oriented context the proportion of the product vs. the service defines the design methodology. In a result-oriented theme, service design is prioritized since the customer seeks a value or result rather than a product. In this context the products serves only as a way of fulfilling the service (Tran and Park, 2014). The overall design process is built on five main pillars:
PSS idea generation: the manufacturer uses customer information made available through feedback, questionnaires, surveys and historical data to evaluate his requirements and how the current offering meets them (Maussang et al., 2007; Tran and Park, 2014). Weaknesses or gaps in answering those requirements form the starting point of the solution. Once an idea is generated, its broad elements are defined and the latter identifies it as a PO, UO or RO offering.
PSS analysis: the idea is weighed against competitors to understand their current stance and what their attitude might be if the idea is realized and launched on the market. Moreover, the solution idea is weighed against the level of technology required to fulfil it and the timeframe needed to implement it. The firm's capability of realizing the PSS idea has to be evaluated and involves: the project team, manufacturing resources, external partnerships, brand image, technical context, products to integrate, economic outlooks and operations (Alix et al., 2009).
PSS development: based on the analysis, PSS scenarios can be imagined. Stakeholders need to be defined according to the life cycle of the product and its interactions with the service. Therefore product-service relations at the Beginning Of Life (BOL), Middle Of Life (MOL) and End Of Life (EOL) of the solution have to be outlined. The values and costs embedded for each stakeholder result from a functional analysis of the sub-activities needed to achieve the design. They are represented through adaptation functions that reflect adaptations and resistances often leading to costs and interaction functions which correspond to the services supplied by the product throughout the lifespan: value (Maussang et al., 2007). To each function corresponds a solution represented by Functional Bloc Diagrams (FBDs), the Function Analysis System Technique (FAST) or the Structured Analysis Design Technique (SADT). The goal is to visualize the products and services that interact with various stakeholders in order to provide the solution design.
The outcome goes through a detailed inspection to evaluate its costs and benefits to each stakeholder and thus to obtain a comprehensive assessment of the solution and a clear vision of its inputs and outputs, interactions, advantages and restrictions.
PSS delivery: concerns the logistics and required workforce to facilitate the delivery of the PSS to the customer. The design is first tested with a limited number of customers in real-life circumstances (Marques et al. 2013) for 'last-minute' adjustments before a marketing campaign is launched. Additionally, the required supporting processes for its delivery, use and retirement are described (Reim et al., 2014).
PSS sustainability: end-of-life considerations must include recycling, reuse or remanufacturing tactics based on innovative service strategies that allow optimal resource utilization. The product may be re-introduced in other scenarios if the solution is product-centred. The service should facilitate take-back strategies if the solution is use-centred. And a result-oriented solution should be founded on sensible solutions that provide the optimal customer-environment requirements trade-off mitigating unwanted rebound effects: in such systems the PSS provider is free to deliver the result in any means possible and thus environmental consciousness should be prioritized (Baines et al., 2007; Tran and Park, 2014). A holistic approach for the PSS development helps engineers to draw up its ecological profile, providing feasible solutions to augment its environmental performances over mandatory issues (Fargnoli et al., 2012 and 2013).
Table 3 presents the considered models and emphasizes the 'divergences' from one model to another.

2.3 Research issues

To better analyze the different approaches in the literature, and compare them in a homogenous manner, a reference framework is needed. Product development is considered the foundation of service development (Shekar, 2007) as well as PSS development (Aurich et al., 2004; Oliva and Kallenberg, 2003). Product design and development has adopted an efficient and proven structure to guide the design process, known as the design science approach (Hubka and Eder, 1988). Its effectiveness has been proven throughout years and given the relationship of product design with service and PSS design, the design science structure will be adopted to categorize the activities of a PSS and hence the PSS model. Tonelli et al., (2009), Tran and Park (2014) and Schmidt et al., (2015) argued that a four-phased product design process is effective for a PSS application. Conventional product design starts with a planning phase where ideation occurs and the task is elaborated. The second phase regards the design of the concept where the functions are specified, and the inputs and outputs are defined. The concept instances are evaluated and the most promising is selected. In a third phase, embodiment, the components required to develop the concept are outlined. The design characteristics are described and the products components are determined. Fourthly, the resulting product is manufactured as a prototype, which undergoes testing and refinement. Once approved, the product is made available on the market.

For these reasons, the design process scheme deriving from the schemes proposed by the ISO/TR 14062:2002 report (Fargnoli and Kimura, 2007; Fargnoli, 2009) and the IEC 62430:2009 guide was used. Moreover, to provide an objective and more precise comparison of the design models presented in Table 3, we applied the assessment criteria based on the ones proposed by Vasantha et al., (2015) and Tran and Park (2015). More in details:

- A score of "0" is awarded if the criterion is absent in the design model (for clarity and ease of reading, the score of "0" will be omitted and represented by a blank case).
- A score of "1" is awarded if the criterion is mentioned but not detailed.
- A score of "2" is awarded if the criterion is mentioned and detailed.

3. Analysis of the Models

The PSS design models presented in Table 3 are thoroughly examined to define the arrangement on which they are built. The activities on which the scoring was carried out are described as follows:

1. Ideation:
    a. Identifying the customer: the PSS offering has to be adapted to an adequate customer. PSSs are distinguished for providing customized and personalized solutions to its customers. Hence, the customer must be accurately defined (Lee et al., 2011).
    b. Identifying customer requirements: the customer has to be understood through qualitative and quantitative methods. The goal is to define the requirements of the holistic solution and its components. Given the complexities of a PSS, understanding customer requirements require an in-depth analysis of his experience and the collaboration of multidisciplinary teams (Carreira et al., 2013).
    c. Identifying the customer's quality criteria: a PSS delivers value through its product and its service that enhance the overall experience. Accordingly the elements judged critical to quality should be defined from both a product and a service perspective.
    d. Identifying the customer's activities: to fully grasp the customer's involvement, the activities involving him have to be understood and perceived from his point of view.
    e. Proposing a solution idea: the idea must address the customer's needs in a comprehensive manner. Life cycle considerations are emphasized in PSSs to provide ideas and solutions on a holistic basis.
    f. Feasibility analysis of the proposed solution: a full feasibility study consists of an economic analysis for profit-cost evaluation, a technical analysis to assess the production methods needed, a location analysis to examine the distribution strategy, a manpower analysis to examine the workforce and skills required, and a sensitivity analysis to address the risk-to-reward ratio and the sensitivity to competition. A feasibility analysis is vital as a PSS aims on benefiting the customer as well as the manufacturer.
2. Conceptualization:
    a. Breaking down the idea: the idea has to be decomposed into modules where the realization of each contributes to the holistic solution (Maussang et al., 2009; Zhang and Haapala, 2011).
    b. Identifying PSS providers and receivers: a PSS requires actors/stakeholders to fulfil it. Several stakeholders are involved and can be defined as providers and receivers according to whether they are affected or influenced by the PSS and whether they are at the providing or receiving end of the value

(Trevisan and Brissaud, 2015)

c. Identifying the product and service elements: according to the concept decomposition, products and services are regarded as the means to fulfil each defined function. The products and services are related to the PSS stakeholders mentioned in 2.b as each includes specific products and can deliver particular services.
d. Evaluating the concept: a PSS concept is weighed against the manufacturer's capabilities from one hand to identify which activities he can perform and which activities are outsourced. Moreover, a PSS is notorious for incurring environmental benefits. To ensure the environmental feasibility of the concept a preliminary life cycle analysis is required to validate the chosen concept or select an alternate one.

3. Embodiment:
   a. Process mapping and defining design activities: the activities required to design the product and the service have to be defined and laid out in a concise manner. The flow of activities has to be clear and understood by all the involved parties.
   b. Defining activity inputs, outputs and constraints: the design activities, encompass inputs, outputs and constraints. A holistic view of the process allows a better understanding of the activity map in order to visualize the constraints and thus optimize the design activities.
   c. Mapping the stakeholders and their interactions: the identified PSS providers and receivers are portrayed to identify the interactions and touch points between them (Kim et al., 2010).
   d. Assessing the company's position vis-à-vis the stakeholders: the manufacturer can gauge which factors and elements should be reduced and which should be increased to maximize its earnings.
   e. Defining the value network: the activities and the stakeholders are combined into one diagram to outline the values and costs that an activity allocates to its stakeholders.
   f. Life cycle analysis: at this stage, the environmental impact of the PSS can be reviewed at a detailed level and deliver accurate results in terms of environmental sustainability.
4. Validation and market launch:
   a. Product testing: the product is manufactured as a prototype and its attributes and performance are evaluated.
   b. Service testing: the service is assessed according to the experience it delivers. Normally a closed group of customers is selected for this task (Bruhn, 2006).
   c. Evaluating testing results and refinement: the results from product and service testing are assessed and enhancements are carried out to adjust.
   d. Marketing and launching: the marketing personnel develop a marketing strategy to introduce the PSS on the market.

The design models shown in Table 3 were evaluated against the activities shown above. For one model, the maximum attainable score is 40 and corresponds to the allocation of "2" for each of the activities (Table 4). The comparison is then illustrated according to these results in Figure 1. The results show that none of the models is comprehensive confirming the inexistence of a unified PSS design model as indicated by Baines et al. (2009), Beuren et al. (2013), Matschewsky et al. (2015) and Mourtzis et al. (2016).

Table 3. PSS design models

Model/Framework	Characteristics of the model	References
1. Framework for PSS Design for Manufacturing Firms	The framework consists of four stages: starting, definition, realization and closing. The manufacturer's business and organizational aspects are highlighted. The company's market position towards its customers and rivals direct the design of the solution, the value proposition and the development strategy.	Alix and Vallespir, 2010. Touzi et al., 2013.
2. Innovative Product Advanced Service Systems Framework	The Innovative Product Advanced Service Systems (IPASS) framework is built by focusing on the customer, the market segment he represents and his requirements. The model concentrates on innovative measures to meet the customer's requirements. The framework uses Quality-Function-Deployment (QFD) to define the customer requirements and the product and service components to fulfil them. The selected components are then measured against the manufacturer's capabilities and the existing customer relationships.	Lee and Abu Ali, 2010.
3. Customization Framework for Road mapping Product-Service Integration	Three stages are outlined: structural determination, functional determination and road mapping. Technological innovation guides the product-service integration. Integration can be applied by focusing on the tangible product or the intangible service and at different stages of the design. Once the design is developed, a road map is used to evaluate it and its impact on the market.	Chadee and Pang, 2008
4. Business Model Design Methodology for Innovative PSSs	A business model methodology for innovative PSSs based on generating new ideas starting from the current product and aiming towards an integrated offering. The model revolves around modularity generating design blocks. The combination of the blocks to finalize a PSS consists of: identifying product and service elements, selecting the model's theme, value creation, value proposition and implementation.	Morris et al. 2005. Masanell and Ricart 2010.
5. Systematic Design Framework for PSS	The framework relies heavily on the service. Four sequences are visible: value modelling, service activity design, interaction/touch-point design and experience management. The requirements of the stakeholders are defined and help define the value to deliver. The needed activities to fulfil this value are designed with consideration of the stakeholders' interactions with the value. Once the context is defined, concepts are generated and decomposed into sub-elements to develop independently. The service blueprint is used to illustrate the flow of activities throughout the entire process.	Shostack, 1987 Galvao and Sato, 2006. Kim et al., 2013.
6. Methodology for PSS Development	PSS development in this context relies on four pillars: organizational readiness, planning, design and post-processing. The core is a cultural change within the company to acclimatise the design and development processes to a PSS offering. This enables eyeing a solution from a customer and a manufacturer's points of view. Therefore, both life cycle stances are embedded to pinpoint the involved actors and their sought solutions. Product and service modelling allows describing their feature from a high-level view without detailing the activities. Testing concludes the design stage and is followed by market launch. The cycle continues as a Plan-Do-Check-Act (PDCA) plot for continuous improvement.	Davies et al., 2006. Tukker and Tischner 2006. Maussang, et al., 2009. Marques et al., 2013.
7. Canvas Business Model Framework	Evaluation of the specifications and requirements to shift the production towards PSSs addressed from a business model stance. Three axes are described. The business context regards assessing the company's resources and market situation vis-à-vis the possible solution's pros and cons and their impact on its situation. Defining the PSS characteristics, as in the way to provide value (products and service needed), and creating value superior to that of a conventional product, the PSS delivery channels, profit streams, required	Isaksson et al., 2011. Schuh et al., 2009. Osterwalder and Pigneur, 2010. Barquet et al., 2013.

	activities and how to improve their performance, and specifying the actors' roles and responsibilities throughout the PSS life stages.	
8. Practical Design Framework	The framework concentrates on the existing product and service design processes and is flexible to be applied to different types of PSSs. User involvement and the structure of the integration is viewed from a life cycle perspective where each activity of the life cycle is to be defined and described.	Aurich et al., 2004. Aurich et al., 2006. Shekar, 2007. Tran and Park, 2014.
9. Generic Competitive Process Framework	The framework defines PSS operation into five parts: contracts, marketing, networks, design and sustainability. The value delivery mechanism is defined by customer-manufacturer relationships from a supply chain perspective to include suppliers and distributors. The design process is documented and described, and the environmental sustainability issues a PSS addresses are exposed. Each of the five parts of the framework is customizable according to the manufacturer's requirements and perspectives.	Casadeus and Ricart, 2010. Reim et al., 2014.
10. PSS design exploration process	This PSS design approach requires congregating the manufacturer's methodology, the service tactic, the customer's perception, and the infrastructure to generate an integrated product-service solution capable of delivering its intended value. The manufacturer's role lies in combining his setting with the client's requirements and the available technology to develop a valid PSS. To do so, the customer's requirements are weighed against the firm's resources. The customer is brought in to participate in generating an idea and later a conceptual prototype. If validated, the PSS is launched on the market. This model however is very high-level and only provides a general outline of the process.	Morelli 2003, 2006.
11. PSS framework for intensified use	The framework seeks to maximize the PSS's output in terms of value throughout all the phases of its life cycle. The environmental aspects are stressed in this framework To address the environmental factor of the design; the PSS has to simultaneously consider the environment and the customer's requirements. Product and service requirements have to be defined, their viability tested, operations have to include the environmental side of things via an extensive analysis of the PSS stages. Modelling the possible scenarios guides the design process. Additionally, end-of-life considerations have to be adapted to the PSS.	Gehin et al., 2009. Gronroos, 2011. Amaya et al., 2014.
12. Kansei engineered PSS model	The Kansei framework positions the customer at the centre of the design. Firstly, the process defines the setting of the application and the customer's demands from it. The embedded components such as the products, the services and their associated experiences are analysed to identify the user's unfulfilled needs or unmet requirements. The product-service combinations are constructed to answer those needs.	Carreira et al., 2013.
13. Flexible PSS design framework	The framework addresses the PSS design from a business model perspective where the totality of the design to shift from product to PSS development can be broken down into basic elements. After identifying the customer, designers define the main service components and processes deemed of the PSS. The design process consists in recognizing the principal stakeholders of the system, grasping the customer's requirements, defining its elements, and designing the offering.	Zine et al., 2014.
14. Integrated PSS model	The model distinguishes three phases to successfully design a PSS solution. Initially, a strategic phase consists in identifying customer requirements and the manufacturer's feasibility to provide a basis for the conceptualization phase. The second phase consists in developing of the concept and then the detailed design of the solution to measure its performance. Thirdly, the developed solution is introduced on the market.	Maussang et al., 2009. Trevisan and Brissaud, 2016

Table 4. Analysis of the PSS design models according to their embedded activities

	1. Idea generation and task analysis						2. Conceptual design				3. Detailed design						4. Testing and marketing			
	a. Identifying the customer	b. Identifying customer requirements	c. Identifying the customer's quality criteria	d. Identifying the customer's activities	e. Proposing a solution idea	f. Feasibility analysis of the proposed solution	a. Breaking down the idea (functional oriented)	b. Identifying PSS providers and receivers	c. Identifying the product and service elements	d. Evaluating of the concept	a. Process mapping and defining design activities	b. Defining activity inputs, outputs and constraints	c. Mapping the stakeholders and their interactions	d. Assessing the company's position vis-à-vis the stakeholders	e. Defining the value network (values and costs)	f. Life Cycle Analysis	a. Product testing	b. Service testing	c. Evaluating testing results and refinement	d. Marketing and launching
1. Framework for PSS design for manufacturing firms	2	2	2		1	1	1				1		1		1					1
2. IPASS framework	2	2	2		2	1	2		2	1	1									
3. The customization framework	1	1			1	2	2		2		1									
4. Business model design methodology for innovative PSS	2	2	1		2	2			1				2							1
5. A systematic PSS design framework	1	2		2			1				2	2	1		1					
6. A methodology for PSS development	1	1	1		1	1	1	1	1								1	1	1	
7. Canvas business model framework	2	2	2	1		1		1	1				2	1						1
8. Practical design framework	1	1			1	1			1	2	2	1				1	1	1	1	
9. Generic competitive process framework	1	1	2	1				2	1			2	1	2		1				1
10. PSS design exploration process	1	1		1			1	1	1			1	1		1					
11. PSS framework for intensified use		1	1						2	2				1		2			2	
12. Kansei engineered PSS model	2	2	1	1		2			2		1									
13. Flexible PSS design framework	1	1				2			2		2		2					1	1	
14. Integrated PSS model	1	1		2			2	2	2		2	1	2		2					

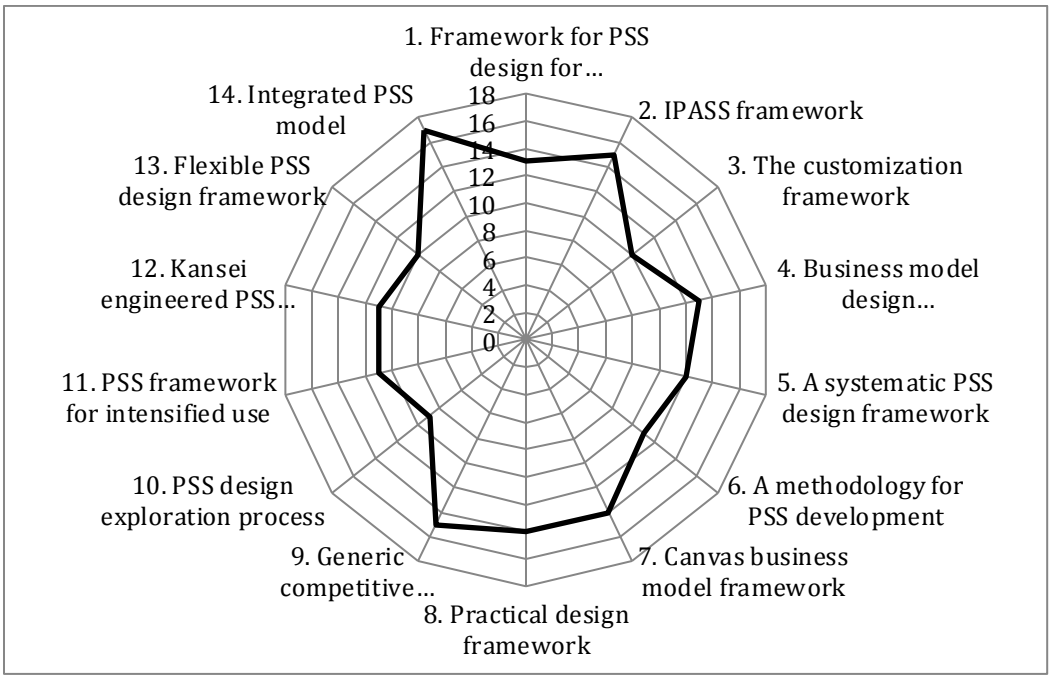

Figure 1. Comparison of the current PSS design models

4. The Design Process For PSSs

From the analysis of the frameworks presented in the earlier section, we propose a comprehensive design process for PSSs. Tonelli et al., (2009), Tran and Park (2014) and Schmidt et al., (2015) argued that a four-phased product design process is effective for a PSS application. The process, relying on design science is renowned for being an effective junction of design activities and strategies (Fargnoli and Kimura, 2007). Based on the latter, the proposed design process comprises of four pillars: Ideation and Planning, Concept Development, Detailed Development, Testing and Market Launch.

4.1 Ideation and Planning

A PSS seeks to deliver value to the customer as well as the manufacturer. Hence, a PSS idea needs to enclose both stakeholders. The idea, generated by the manufacturer necessitates answering the customer's latent and unanswered needs in a feasible and profitable manner for both parties.

The customer needs to be identified according to his category, relationship and requirements. Customer categories vary according to customer type (business-to-business, business-to-customer) topographical diffusion (domestic, local, international) and market characteristics (Lee et al., 2011). Moreover, the respective customer strategy is described: PSS development or business diversification.

PSS development consists in delivering a new solution to an existing set of customers. The solution seeks to replace the existing offering by means of updates or replacements. Business diversification on the other hand consists in delivering new solutions to new markets. The diversification can be horizontal based on product extension where the current product is supplemented by add-on services; or lateral where the offering is novel utilizing state-of-the-art innovation and technology. Business diversification incurs risks given that the manufacturer has no prior experience with the new markets. Accordingly, utilizing existing customer relationships can be the cornerstone of a safe market expansion. Providing incentives in terms of overall experience and economic value maintains and retains existing customers. Customer surveys with the collaboration of suppliers, retailers and distributors aid in understanding the customer's requirements. Interviews and consultations define the customer's quality drivers on which he judges the current experience and his future aspirations. Accordingly, competitors are assessed and the existing market gaps can be exploited to penetrate new markets and acquire new customers.

In order to provide a solution that meets the customer's objectives, the manufacturer has to assess his current

situation in order to propose an idea that delivers value for both parties. A life cycle approach is recommended to propose a satisfactory solution vis-à-vis the manufacturer's current line of products and services. The product-service integration and hence the PSS type (PO, UO or RO) depends on the manufacturer's position on the market versus his rivals and the potential of his business model. Life cycle thinking intervenes to provide a holistic assessment of the PSS in terms of satisfaction against sustained costs. Each requirement to meet must be allocated with the essential resources for its fulfilment: manufacturing operations, workforce, training, distribution channel, product and service processes etc.
The requirement area that the manufacturer cannot meet may be outsourced. Hence the stakeholders network from a supply chain perspective is identified to enable a better allocation of the resources and defining the cost structure.
To summarize the ideation and planning phase, a feasibility analysis is recommended to evaluate the feasibility and profitability of the proposed idea. Initially a macro-assessment is advised, typically, a SWOT helps qualitatively visualize the potential of the solution and the possible obstacles to its realization (Marques et al., 2013).
An economic analysis examines the manufacturer's business process and financial aspects such as fixed and variable costs, and expected profits. A technical analysis inspects the manufacturing capabilities. A location analysis details the distribution channels and logistics as well as the transportation requirements. A labour analysis assesses the human resources such as the available workforce and the training and competences needed. Lastly, a sensitivity analysis depicts the impact of external (competitive environment, pricing, sales volume etc.) and internal factors (development costs, production costs, PSS performance etc.) on the overall value of the PSS offering.

4.2 Concept Development

The proposed idea, once validated, enters the conceptual stage. The idea is embraced as a main function that can be decomposed into sub-functions. The elaboration of each sub-function is a gradual progression towards the comprehensive concept. Current advances in the conceptual development of PSS solutions are limited to a functional analysis approach disregarding the stakeholder's involvement and overlooking product-service compatibility within the concept (Maussang et al., 2009). Therefore, an adaptation of morphological matrices to a PSS context encloses the function, its sub-functions, the service and product elements of each, and the involved stakeholders (Fargnoli et al., 2006; Geum et al., 2011b; Tukker, 2013). In conventional product design, a function is decomposed and each sub-function is assigned the possible means to realize them. This approach allows narrowing down the options towards specific ends. In a PSS setting, the means are represented by activities involving products and services, utilized by PSS providers and receivers. PSS providers are defined as the stakeholders delivering value while PSS receivers are obtaining it (Figure 2).

Function	Service provider/receiver	Activity					Product elements			Service Elements		
PSS sub function A	SP 1	SP-a1	SP-a2	SP-a3	**SP-a4**	SP-a5	**P1**	**P2**	P3	S1	S2	**S3**
	SP 2											
	SR 1	SR-a1	SR-a2	**SR-a3**	SR-a4	SR-a5						
	SR 2											
PSS sub function B	SP 3	SP-a6	**SP-a7**	SP-a8	SP-a9	SP-a10	P4	P5	P6	S4	**S5**	S6
	SP 4											
	SR 3	SR-a6	**SR-a7**	SR-a8	SR-a9	SR-a10						
	SR 4											

Figure 2. Morphological matrix in a PSS setting

A PSS idea, assimilated to a function is decomposed into two sub-functions, A and B. For PSS sub function A, two PSS providers SP1 and SP2, and two PSS receivers, SR1 and SR2, are identified as the possible stakeholders involved in A. The activities the providers can perform are listed as SP-a1 to SP-a5, while the receivers can perform activities SR-a1 to SR-a5. The products that can be used are P1, P2 and P3 while the probable services are S1, S2 and S3. The fulfilment of A, as conceived by the designers will involve SP1 and SR2 carrying out their respective activities SP-a4 and SR-a3 which require the product components P1 and P2, and the service component S3. PSS

sub function B is defined using an analogue approach to A. The PSS concept function results from the fulfilment of its two sub-functions described above. Each viable combination of sub-functions specifies a defined concept. Different combinations result in different concept instances. The acceptance or rejection of the chosen concept depends on its feasibility and profitability on a financial and environmental basis. Hence, a life cycle approach is recommended for a thorough evaluation of the concept. PSSs gained recognition as more ecological manner of delivering what a product provides. A holistic consideration of the life cycle allows a limited yet indicative evaluation of the concept's outcomes (Figure 3). If approved, the concept goes to the embodiment stage where its details are developed. However, if the concept is rejected, an alternative will be chosen using a different combination of stakeholders, products, services and activities from the morphological matrix.

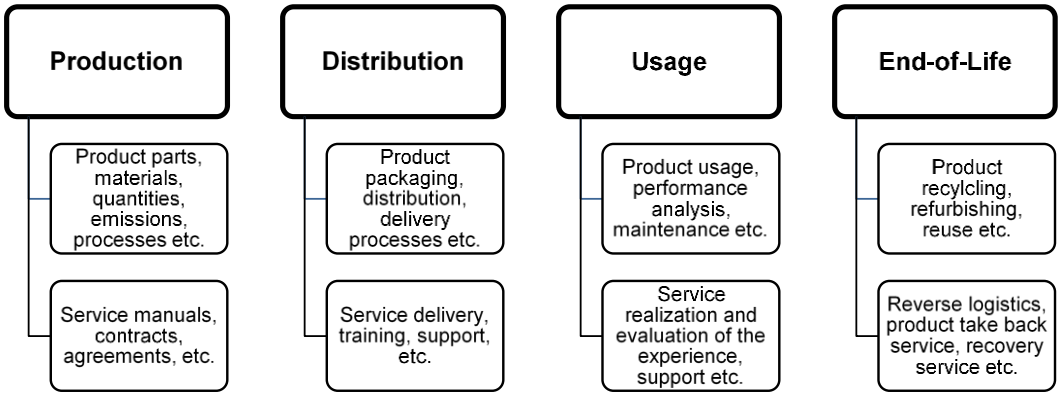

Figure 3. PSS life cycle considerations at a conceptual stage

4.3 Detailed Development

The selected concept from the previous stage enters an embodiment phase. Embodiment specifies the product-service integration, the process map, the stakeholders' network and interactions, the value configuration network and the environmental impacts of the system.

A PSS positions the customer at the centre of the design (Reim et al., 2014). Accordingly, the stakeholders are defined and mapped out to identify the relationships that tie them. Identifying the stakeholders arises from defining the economic interests in question, namely the providers and the receivers: the involved suppliers and distributors and the possible external stakeholders that may influence the PSS. Possible representations of the stakeholders include the actor network map, the flow model, the persona tool (Sakao and Lindahl, 2009), etc. The activities defined from the conceptual stage are then mapped out with the constraints and supporting processes required to achieve them. Service blueprinting is a widespread tool that visualizes the activities and their level of visibility: activities occurring between the customer and the product or service, activities occurring between the customer and the manufacturer's customer oriented personnel, and activities occurring amongst the manufacturer's workforce (Hajdu, 2012). To represent the constraints and additional elements related to the activities, the Structured-Analysis-Design-Technique (SADT) or the Function-Analysis-System-Technique (FAST) can be implemented (Trevisan et al., 2015). Based on this, each activity is assigned to its corresponding stakeholder (s) and the product and service elements are identified as inputs and outputs, as shown in Figure 4.

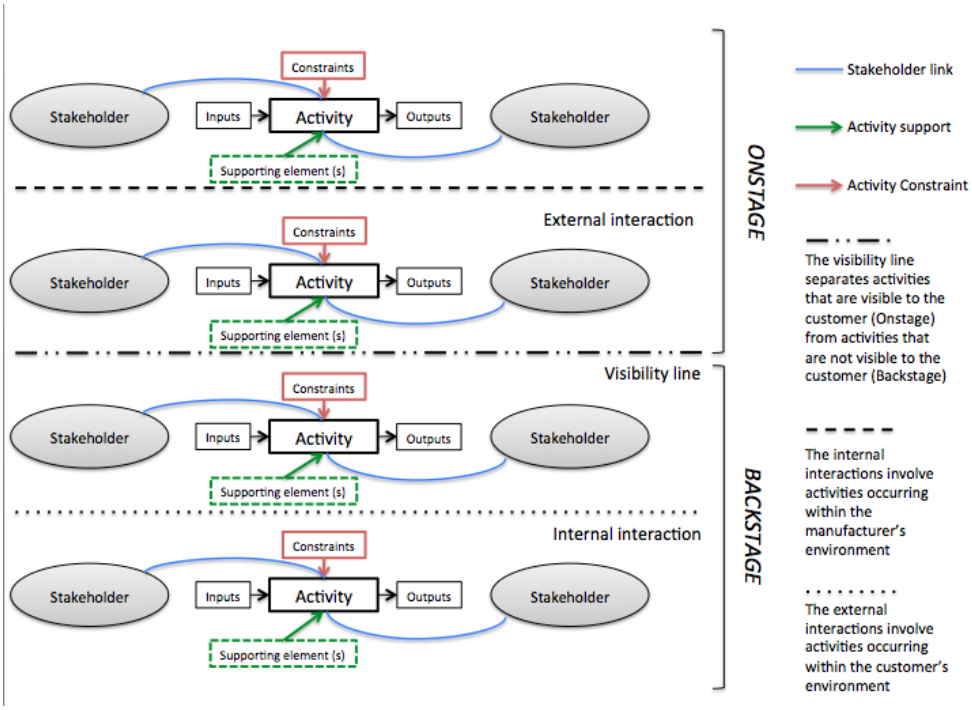

Figure 4. Activity mapping

Constraints and supporting elements, if existing, are also shown to aid the manufacturer in identifying the activities and elements that should be emphasized or reduced. Having visualized the activities and the stakeholders' interactions with them, design milestones are discussed and arranged to ensure a consistent flow. The flow must include the values and costs each activity incurs.
Based on Maussang et al. (2009), we described the flows as interactive functions when value is added and adaptive functions when costs or reduced value is induced due to constraints or mandatory adaptations (Table 5).

Table 5. Cost and value analysis of the activity flows

PSS Provider	PSS Receiver	Activity (1...n)	Activity description	Inputs	Outputs	Constraints	Supporting elements	Value	Cost
Stakeholder 1	Stakeholder 2	Name of the Activity	Description of the activity	Activity inputs (products, energy, information, services etc.)	Activity outputs (products, information, services, etc.)	Limitations and hindrances	External processes that assist in the function realization	Revenue or profit generated (financial income, stakeholder satisfaction etc.)	Fixed and variable costs of manufacturing, delivery etc.
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Providing Stakeholder of activity (n)	Receiving Stakeholder of activity (n)	Name of activity (n)	Description of activity (n)	Inputs of activity (n)	Outputs of activity (n)	Limitations and hindrances of activity (n)	External processes of activity (n)	Generated value of activity (n)	Embedded costs of activity (n)

Positive environmental impacts from providing a PSS are not inherent. Hence, evaluating the environmental features of each activity is essential to a PSS to avoid unwanted and damaging effects (Tukker, 2013). At this stage of the design, a detailed environmental assessment can be carried out from a life cycle perspective (Aurich et al., 2006). A valid and widespread method is the Eco-Indicator 99 (EI99). The EI99 is a damage-oriented technique assessing the impacts of carcinogens, respiratory organics and non-organics, climate change, radiation, ozone layer depletion, eco-toxicity, acidification, land use, minerals and fossil fuels (Zhang and Haapala, 2011). The assessment activities incorporate the goal, scope and life cycle inventory analysis elaborated above in five key sets:

1. Establishing the objective of the EI calculation by describing the product/service component at stake and defining whether it is a single product analysis or a comparison vis-à-vis the needed level of precision and accuracy.
2. Describing the life cycle stages such as the type of production, processes involved in manufacture, use, waste and disposal related scenarios.
3. Quantifying materials and processes: performance is calculated in terms of functional units (quantity, temperature, duration…) specific for a given process. Any missing information can be meticulously estimated and returned to, once the analysis is finished to reflect on the assumption made.
4. Documenting the materials and processes used with their respective amounts and obtaining the relevant EI values for each. Multiplying the latter two and summing up the results calculate scores.
5. Interpretation of the results and validation (Goedkoop and Spriensma, 1999).

4.4 Testing and Market Launch

The final stage of testing and market launch, in other words validation, is absent in the PSS literature and is considered as the keystone of the final design phase whether it is a product, a service or a product with integrated services (Berglund and Grimheden, 2011; Coughlan et al., 2007). Given the interdependence of product and services in a PSS environment, the validation method has to be comprehensive to verify the designed correlation in a practical manner in order to assess the suitability of the objective to which the PSS was designed.

A PSS involves products and services, hence a holistic validation and testing is needed. A closed group of customers is exposed to the PSS where the characteristics of the products and the generated experience from the service can be evaluated. From a product perspective, a prototype is manufactured after preliminary testing using computer-aide-design and virtual mock-ups (Laroche et al., 2011; Rosenblatt et al., 2011). From a service point of view, replicating a real-life situation involving the closed group of customers allows designers to evaluate the PSS and receive feedback from the customers to improve current interactions and capture an unexpected or missing occurrence (Van Husen and Meiren, 2008).

The testing phase allows refining the PSS through adjustments and modifications to finalize the design. Once the design is settled on, a marketing plan is put in place. In particular, three considerations are required: the manufacturer and providers, the customers and the context (Vezzoli et al., 2015).

The manufacturer and providers: PSS's complexity compared to traditional product development requires a cultural vision to be established and a holistic participation of all the stakeholders. In detail, the stakeholders have to be trained and prepared to deliver the PSS solution, fully grasp the product-service components and develop metrics to measure the delivery process and continuously seek improvements in order to build long lasting customer relationships.

The customers: customer awareness is fairly minimal regarding integrated solutions. This leads to risks, costs and responsibilities to be in a 'grey area'. For instance a lack of understanding and knowledge may lead to consumers comparing the initial cost of a PSS to the transactional cost of a stand-alone product without considering the additional charges encountered with the product, which are avoided when opting for a PSS (i.e. disposal, maintenance, repairs, etc.). Customer behaviour has to shift towards an ownerless, functional setting to achieve satisfaction. Not all needs can be answered by an ownerless solution and thus customer sensitivity is of high importance.

The context: considering stakeholders in their context allows visualizing their behaviour in a holistic manner with the dependencies and interactions concretized. Customer habits, financial resources and value perception are amongst the dominant obstacles to PSS implementation as the changes required are radical. Consequently acceptance has to be staged on a long-term basis with incremental smart steps leading to its full deployment. Despite extensive market research and customer study, success stories lie heavily in the business-to-business (B2B) realm highlighting the difficulties encountered in fully engaging the business-to-customer (B2C) context. A B2C market requires a socio-psychological approach, which is why thorough testing is fundamental to capture and relate to those aspects.

Additionally, governments should encourage PSS proposals by creating advantageous economic conditions to favour the viability of integrated product-services as well as increasing customer and business awareness about the benefits of PSSs notably financial profits and environmental sustainability opportunities. Measures to achieve this goal require internalizing environmental and external costs such as emission taxes and charges, extending manufacturer responsibility, and developing informative policy measures such as promotional campaigns, eco-labelling etc. (Ceschin and Vezzoli, 2010).

5. Conclusion

The research analysed the state of the art of PSS design methods and processes, depicting two main categories: a business model design process and a technical product-service design process. Each design process was evaluated by defining the activities it involves, and the design stage that includes them. The result of the review allowed us to define all main activities, which should be carried out to develop an optimal PSS solution. The inclusion of them into the four-phase design process deriving from the design science approach, allows engineers to have at their disposal a comprehensive tool, whose effectiveness is widespread and proven in design activities.
The authors acknowledge that the paper is limited to a theoretical design process but are confident in its validity. The existing design processes in the literature are demonstrated with practical case studies; hence the activities they encompass are feasible and viable. Further research work is needed to address the practical testing of the proposed approach to delineate and validate its feasibility. The testing should include product-based, use-based and result-based scenarios, to bring to light its strengths and limitations in different PSS contexts.

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