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Abstract

Manufacturers have started exploiting the benefits of Internet-of-things and Artificial intelligence to offer solutions known as "Smart PSS." Recently, smart PSS engineering frameworks have begun appearing. Those frameworks lack guidelines on how to conduct risk management activities throughout the design and development of a smart PSS solution. This paper presents a framework aimed at designing Smart PSS solutions, necessary value networks to deliver the smart PSS solution, and the economic models associated with these value networks. The framework is currently being applied to a case study involving a gas boiler manufacturer.

Keywords: Smart PSS engineering, Risk management for Smart PSS, Smart PSS value network

1. Introduction

The continuous growth of Internet-of-things (IoT) and Artificial Intelligence (AI) applications has caused a shift in the concept of Product-Service Systems (PSS). A new type of PSS has arisen over the last years: the smart PSS. Valencia Cardona, 2017 [1], defines Smart Product-Service Systems (PSS) as "the integration of smart, connected products and e-services, presented to consumers as single solutions to satisfy their needs." Manufacturers have been motivated to adapt their traditional PSS offers into smart PSS solutions for two main reasons: on the one side, the need to differentiate from the competition and deliver added value to their customers; on the other side, the fact that the processing of data obtained from connected products, can be used to improve the performance of products and create new services.

Designing PSS, solution, either traditional or smart is a complex process. Managing this complexity requires a structured design approach. This structured approach is known in the literature as PSS engineering, which is extended to Smart PSS literature as Smart PSS engineering. The purpose of this structured approach is to guide decision-makers and designers through a series of methods and tools. This approach enables one to visualize the inputs and outputs of each step of the design process. Generally, a traditional PSS engineering starts with the customer requirement generation. Then, the design team executes the planning, engineering, and implementation activities of the traditional PSS offer. Due to the novelty of smart PSS solutions, the vast majority of PSS engineering frameworks available in the scientific literature are aimed at assisting the design of traditional PSS offers and, consequently, the number of engineering frameworks fully dedicated to Smart PSS remains limited. Moreover, in such an uncertain context, planning and management, planning and management methods need to include resilience (and by opposition risk management) issues, to provide robust, adaptable methods to support strategic decisions.

To contribute to one step forward towards smart PSS engineering framework, this paper puts the focus on risk management along the design and engineering process. Indeed, the design of smart PSS is confronted to various important types of risks, typically linked to (i) data, information and knowledge sharing, but also to (ii) economic value sharing among actors of the smart PSS value network. However, despite the maturity of traditional PSS engineering frameworks, the literature on risk management in the early design phase of PSS offers is sparse.

Although risk management is popular in industrial and logistics systems and has been applied to PSS management, to the best of our knowledge there is no framework having suggested how to perform the identification, assessment, and control of risks in the early design phase of both traditional PSS solutions and Smart PSS solutions, in an explicit manner. When and how to execute these risk-management activities in the design phase of both a traditional and a smart PSS solution is still unclear. Often, financial risks and risks associated with the performance of the ecosystem of the Smart PSS solution are neglected in the literature. The research question addressed in this work is how can risk management be implemented in the engineering process of Smart PSS solutions?

This research work aims to propose a risk-oriented Smart PSS engineering framework. The process of engineering Smart PSS solutions presented in this work includes the design of the Smart PSS solution, the definition of alternative Smart PSS value networks, and the simulation of the economic models associated with the alternative Smart PSS value networks. The outcomes of this framework are: (i) the prototype of the value proposition; (ii) the prototype of the value exchange mapping of the alternative value networks to deliver the smart PSS solution; (iii) the identification and prioritization of risks; (iv) the definition of strategies to control these risks; (v) the development and test of the smart PSS solution; *and* (vi) the quantitative assessment of the economic models of the alternative Smart PSS value networks under an uncertainty management approach.

Based on a broad state of the art, the proposed framework is the result of the integration of Design Thinking tools, concepts of life cycle approaches of Systems Engineering, and PSS prototyping. A case study concerning a gas boiler manufacturer in the context of energy performance contracting is used to illustrate the proposed framework.

The remainder of this paper is structured as follows: Section 2 presents a literature review on Smart PSS Engineering and how Design Thinking, Systems Engineering, and prototyping have been integrated into the engineering process of traditional and Smart PSS solutions. Section 3 presents the proposed framework and describes the activities of the methodological blocks included in the risk-oriented Smart PSS engineering framework. Section 4 introduces the case study that illustrates the application of the proposed framework.

2. State-of-the-art

2.1 Literature review on Smart PSS Engineering

The design of smart PSS solutions is a subject that has started being recently in the scientific literature. Valencia Cardona and al, 2014 [2] presented the first contributions by documenting the challenges arising in the conception of Smart PSS solutions. Kuhlenkötter and al, 2017 [3] describe the issues that PSS engineering methods must face to design smart PSS solutions. Hagen et al., 2018 [4] explain that PSS engineering methods can be transferable to Smart PSS engineering. However, adaptations are needed to integrate smartness into products and services. Some methodological frameworks have been presented in the literature [5-8] to handle the challenges related to the shift from traditional PSS to Smart PSS engineering. Other frameworks focus on assisting the design of industrial Smart Services [9-11]. Smart Service is defined as "the application of specialized competences, through deeds, processes, and performances that are enabled by smart products" [12].

These frameworks do not address holistically some challenging aspects related to the design of the smart PSS offer: (i) the creation of the value network required to deliver the functionality of the Smart PSS; (ii) risk management associated with the design of these value networks and identification of value for stakeholders participating in the value network; (iii) the consideration of different possible value network scenarios; (iv) the evaluation of the economic feasibility of the smart PSS offer; (v) the review of feedback from stakeholders through the development of the Smart PSS solution and (vi) the need to prototype the Smart PSS offer before its market launch.

The frameworks found in the literature have elements in common such as, the identification of customer needs, the development of the PSS solution following a methodological logic, and the use of prototypes to visualize the system.

2.1.1 Design Thinking and Smart PSS Engineering

Scherer et al., 2016 [13], suggest the applicability of Design Thinking in the design phase of traditional PSS offers. They highlight the fact that Design Thinking translates the articulated and unarticulated customer needs into PSS requirements. Existing Smart PSS Engineering approaches have in common to use design-thinking tools like customer journey mapping and customer personas [5, 7, 8]. These tools are aimed at eliciting stakeholder’s needs and assisting in the definition of the value proposition.

2.1.2 Systems Engineering and Smart PSS Engineering

The applicability and adaptation of Systems Engineering Life Cycle approaches in traditional PSS engineering have been previously addressed. These approaches assist in defining the start, conclusion, and process activities pertinent to the life cycle stages. Pezzotta et al., (2012) [14], conclude that the "WinWin Spiral Model" fits better the characteristics of the engineering process of a traditional PSS. Muller (2014) [15], proposed a PSS development process model. This model is an integration of V-models and sequential models. Maleki et al. 2017 [16], present a tailored adaptation of the V model for PSS development. This adaptation implies the development of two parallel V sub-models, one for the system of interest (SOI) and the other for the enabling system (ES). Previous research on Smart PSS Engineering has not addressed the applicability of Systems Engineering in the early design phase.

2.1.3 Prototyping and Smart PSS Engineering

Ilg et al., (2018) [17] argue the relevance of prototyping a traditional PSS offer. They present a list of existing PSS prototypes. These prototypes are associated with four suitability criteria based on the characteristics of a PSS offer: visualization of the PSS, integration of all PSS elements, customer orientation and integration, and test and validation of the PSS. Some of the prototypes mentioned in [17] have been used in the methodological frameworks aimed at designing Smart PSS offers.

Table 1. Summary of Smart PSS Engineering and Service frameworks.

Smart PSS/ smart service design methodological framework	**Application of Design Thinking tools in the system requirements definition**	**Application of Systems Engineering life cycle approaches**	**Application of PSS prototyping**
[5]	Customer journey mapping and analysis	Not addressed	Service blueprint
[6]	Customer personas	Not addressed	Process chain network diagram
[7]	Customer journey mapping, customer personas	Not addressed	Sequence diagram
[8]	Customer observation	Agile approach	Virtual reality
[9]	Not mentioned	Agile approach	Business model canvas
[10]	User stories	Agile approach	Paper storyboards, APPs mock-ups
[11]	Analyse of customer routines and jobs	Not addressed	Business model canvas

2.2 Literature review on risk management in traditional and Smart PSS engineering

Herzog et al., 2014 [18] introduce a framework for customer-related risk management in the early design phase of traditional PSS offers. Reim et al., 2016 [19] propose a risk management decision-making framework aimed at suggesting risk management strategies to control risks for PSS operation. Risk in the context of Smart PSS design has been addressed in Liu & Ming, 2019 [20]. They apply an extended version of the Failure Mode Effect and Critically Analysis (FMECA) in the design of a smart fridge system. This FMECA analysis is used to identify the potential failure modes of co-implementation of a smart PSS solution. However, standard risk management guidelines for both traditional and Smart PSS engineering are not yet available.

2.3 Gap in the literature

Engineering a smart PSS offer poses several challenges that have not been addressed concurrently:

- The need to deal with unclear and evolving customer and stakeholders requirements. Customer needs understanding in the smart PSS context fits the type of projects that design thinking deals with. These projects are characterized as being human-driven, being poorly defined problems due to the vagueness of the problem to be solved through the smart PSS offer, having a high degree of uncertainty, and being complex problems [8].
- The need for a formal methodological framework to engineer smart PSS solutions.
- The need to develop a model that enables the design team to have an abstraction of the Smart Product-Service System: when developing a product, the design team can determine what the outcome will look like through product drawings. The same idea should apply for the design of the smart PSS solution.

Based on the integration of elements of Design Thinking, Systems Engineering, and PSS prototyping, this paper proposes a contribution, which constitutes a path forward towards the definition of a smart PSS engineering framework. While taking advantage of the added value of these three key areas of PSS design, this approach is based on the three following principles:

1. Iterative prototyping of smart PSS: The Smart PSS solution is tested and validated throughout the whole engineering process, following a structured but flexible process. Cost analysis and risk management activities are incorporated in the activities of the blocks to assure the financial success of the Smart PSS concept in the market.
2. Risk management along the design process: risks are identified, characterized, assessed and monitored continually. This risk assessment guides decision-makers in deciding whether to continue/reformulate the Smart PSS development.
3. Economic value sharing risk modelling & assessment: Risk distribution amongst the actors of the Smart PSS value network is represented, to ensure win conditions for actors involved in the delivery of the Smart PSS solution.

3. Smart PSS Engineering methodological framework

This framework is the result of the review of the existing gaps in the literature, and the feedback obtained from practitioners involved in the design of service-oriented contracts. The proposed risk-oriented methodological framework consists of five methodological blocks, namely:

- A) Elicitation of stakeholder needs
- B) Prototype of the general value concept
- C) Prototype of the detailed value concept
- D) Experimental prototyping of the smart PSS solution
- E) Simulation of the PSS value network scenarios

The application of those blocks do not follow a linear approach, despite the presentation of a sequential list of methodological blocks and the associated tasks with these blocks. Certain blocks can be performed in parallel. There is also the possibility of performing blocks that were previously addressed if the assessment of risks leads to this decision. Validations are conducted in the blocks B,C, D, and E. Based on the results of these validations, the design team can determine if they proceed to continue with the activities of the next block, or if they repeat the tasks of a precedent block. This iterative manner of designing and developing the Smart PSS concept is intended to react immediately to unexpected events that threat value for the involved stakeholders.

The final goal of this framework is to assist Smart PSS designers in deciding the most convenient value network to deliver the functionality of the Smart PSS offer. The questions that the application of the framework looks to answer are:

- What is the value proposition of the smart PSS solution?

- Does the smart PSS solution fulfill customer needs?
- What stakeholders are required to create the value network that will deliver the smart PSS functionalities?
- What are the win conditions for the stakeholders involved in the delivery of the Smart PSS functionalities?
- What are the risks associated with the implementation of the value network?
- What is the most profitable value-network scenario?

This framework follows the logic of the Incremental Commitment Spiral Model (ICSM) proposed by Boehm et al., 2014 [21]. This iterative and incremental framework relies on four principles: stakeholder value-based guidance, incremental commitment and accountability, concurrent multidiscipline engineering, and evidence-and risk-based decisions. The framework proposed in this paper adopts the logic of the ICSM. The outputs of the methodological blocks referenced as A, B, C, and E in figure 1 are analogous to those of the exploration, valuation, and foundation phases of the ICSM.

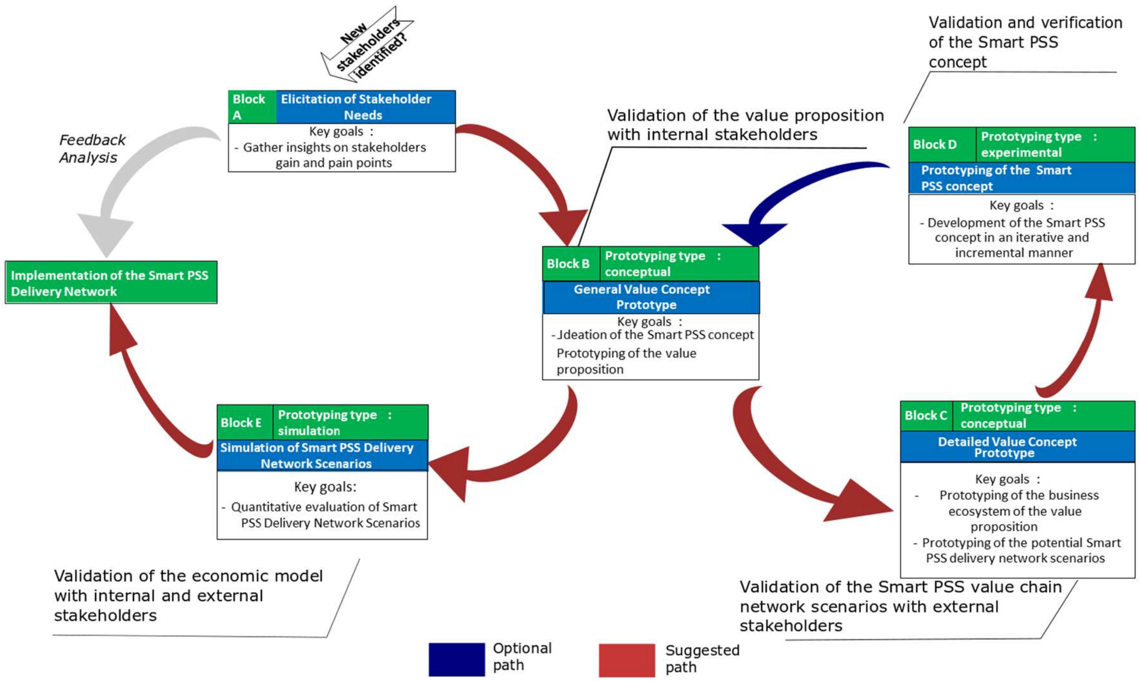

Fig. 1. Risk-oriented Smart PSS engineering framework

3.1 A) Elicitation of stakeholder needs

The first methodological block addresses a deep understanding of stakeholder needs. Design thinking tools such as contextual interviews, ecosystem mapping, customer journey mapping, customer personas, and user stories are used in this block. The final goal is to describe the pain and gain points of the stakeholders to ensure the attractiveness of the Smart PSS solution to be designed.

3.2 B) Prototype of the general value concept

A creativity workshop takes place after having gathered enough insights on stakeholders' needs. The aim of this workshop is to define the functionalities that are going to be offered in the smart PSS contract. Internal and external stakeholders take part in this workshop. During the workshop, the products and services that fulfill the functionalities of the Smart PSS concept throughout its whole life cycle are described. This prototype not only represents the bundle of products and services to be provided, but it also gives an initial overview of the external actors required to deliver the smart PSS functionality.

A modeling tool called PS3M is used for prototyping the value proposition through the representation of the elements of the Smart PSS contract. PS3M is a tool previously developed by the research team. The objective of this tool is to capture and represent all the knowledge necessary for the value proposition, in a structured way. Further information on PS3M is available in [22]. This first prototype enables decision-makers: (i) to ponder the necessary contractual relations with other actors to create the Smart PSS value network and the win conditions of these actors; (ii) to cluster the different ideated services into 'packages of services'; (iii) to consider the different types of clients that could be reached with the formulated Smart PSS concept; (iv) the interaction of physical components with services; and (v) to identify the main cost objects and the revenue mechanisms. The customer activity cycle of the Smart PSS solution is defined in this block.

In this block, the Original Equipment Manufacturer (OEM) assesses the risk level that is willing to assume. Then, an initial risk identification associated with the drafted value proposition is conducted. Three primary sources of risks are analysed and listed in this block. First, those related to the implementation of the new service offers. Some risks might arise because the company does not master all of the capabilities to implement the services that are new to its current value proposition. Besides, the integration of tangible elements manufactured by the company with components supplied by external companies might be another source of risks to be considered. Then, another source of risks is explored, those that threaten the delivery of the PSS functionality, and therefore that affect revenue achievement. Ultimately, the draft of the value proposition is validated with internal actors of the OEM.

3.3 C) Prototype of the detailed value concept

Once the components of the contract(s) have been established, the next iteration consists of planning the prototype of the value network. A mapping of the interactions in the 'as to be' value network is performed. This mapping enables the identification of risks associated with external actors that might affect the smooth operation of the value network/business ecosystem. Risks that endangers the achievement of value exchanges between actors of the value network may also be identified Next, potential scenarios of the Smart PSS value network are identified. These scenarios describe the roles that the actors of the value network can perform in a specific configuration to fulfill stakeholder needs. After that, the processes, activities, and capabilities required to configure the value network scenarios are prototyped on the PS3M modeling toolkit. This prototype eases the identification of the parameters of the economic models associated with these value networks. The drafts of potential scenarios of the PSS value network are validated with external stakeholders.

3.4 D) Experimental prototyping of the Smart PSS solution

This block continues the monitoring of the risks identified in the previous phases. New risks related to the hardware and software components and the integration of those components with service units of the Smart PSS solution are identified. In this block, the smart PSS solution is developed using incremental and iterative work sequences while maintaining constant feedback from the concerned stakeholders. The applicability of agile methods based on these principles of incremental and iterative work in the design and development of smart PSS has already been explored [8]**.** An expected outcome of this block is an estimation of the detailed cost structure of the Smart PSS solution that will be critical to determine the profitability of the smart PSS solution.

3.5 E) Simulation of the PSS value network scenarios

The economic models associated to the value network scenarios are defined. Then, these economic models are simulated on a PSS economic model simulator. This simulator computes the cost, revenues, and profits of each of the scenarios defined in the block C. The simulations are executed within an uncertainty management framework. The outcomes of these simulations enable decision-makers to select the most convenient value network to deliver the smart PSS solution from a multi-actor point of view.

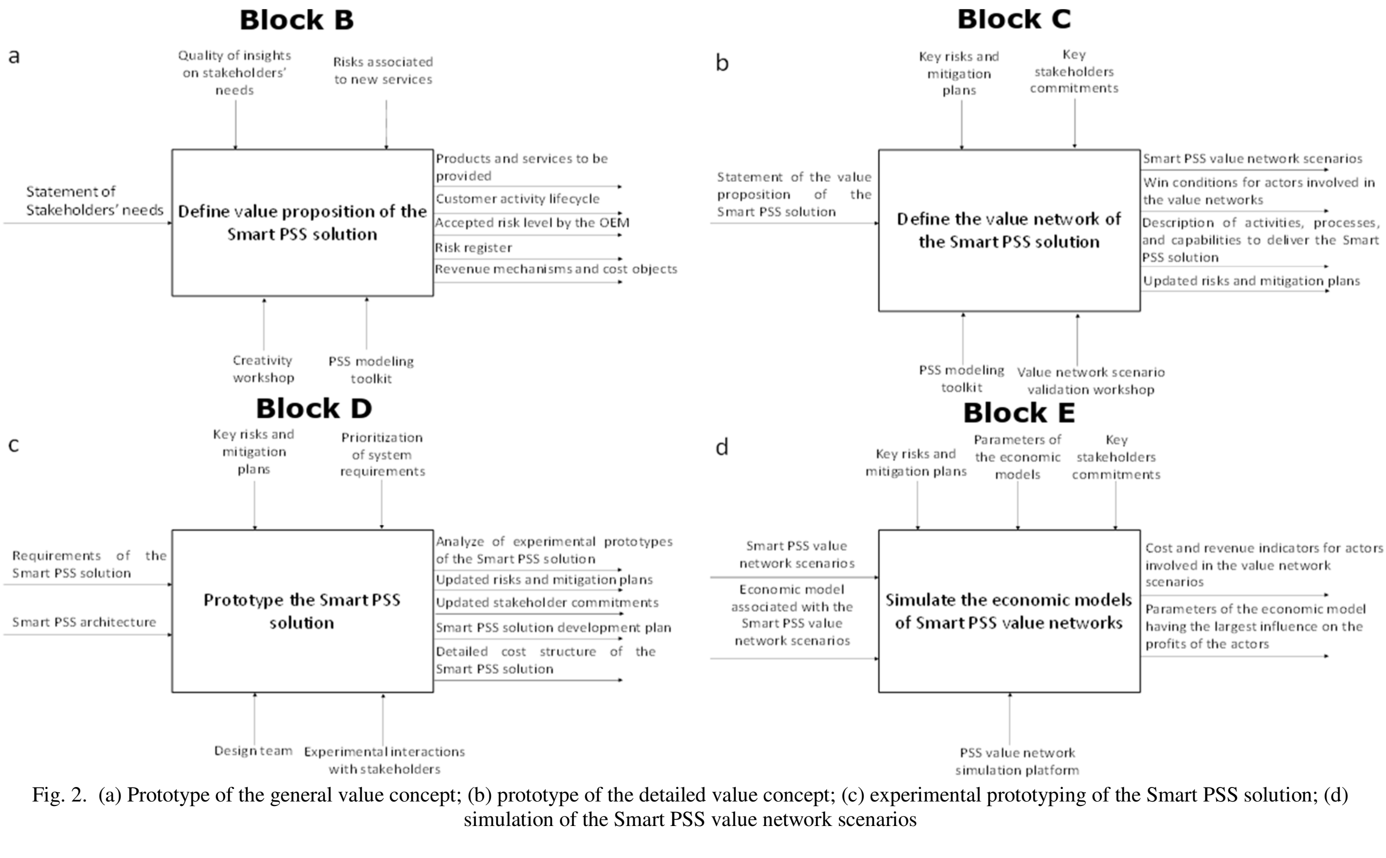

Fig. 2. (a) Prototype of the general value concept; (b) prototype of the detailed value concept; (c) experimental prototyping of the Smart PSS solution; (d) simulation of the Smart PSS value network scenarios

4. Case study: smart PSS solutions in energy performance contracting

In this case, the OEM is a gas boiler manufacturer. The OEM is invited to participate in a bidding process for an energy performance contract. The beneficiary of the contract is a social housing company. The objective of this contract is to guarantee that a housing unit consumes as much electricity as it generates through solar energy. This objective must be attained while ensuring thermal comfort in the housing unit throughout the year. The manufacturer already has a first experience in using IoT to offer a predictive-maintenance service for a fleet of gas boilers. In order to offer a higher value-in-use experience to intermediate and end-users of the heating system, the manufacturer contemplates expanding its current service offer to make the most profits of a 'connected thermal system'. For this purpose, the OEM begins a project to develop a Smart PSS solution aimed at improving the customer experience of social landlords, and other stakeholders, in the operation of energy performance contracts.

4.1 Discussion on the implementation and case study application under development

The framework presented in this work is being applied at present to the case study.

Application of the block A: The first methodological block corresponding to the elicitation of stakeholders' needs has been applied. The research team has conducted contextual and in-depth interviews with different stakeholders, such as, residents of social housing units, facility management directors of social housing companies, and experts in thermal engineering. The results of these interviews enabled the research team to create personas, and identify the pain and gain points of these personas. Then, based on these insights, customer journeys and user stories were created to serve as input for the creativity workshop.

Planned application of the block B: The creativity workshop will take place some months later after the drafting of this work. The value proposition will be prototyped on a tailored version of the PS3M modelling toolkit.

Planned application of the remaining blocks: The prototype of the value network associated with the value proposition prototyped in the block B will be carried out on PS3M. The simulation of the economic models under an uncertainty management framework will be carried out on a tailored version of a PSS scenario analyser platform called PS3A.

5. Conclusion

Smart PSS engineering frameworks available in the literature often address the design of the Smart PSS concept and its value proposition. However, these frameworks do not address some challenges that manufacturers that adapt their product-based value propositions into Smart PSS solutions must face during this engineering process. These challenges concern the creation of a new value network that integrates new actors, e.g, IT infrastructure providers; the management of risks related to this new value chain and the technical aspects of IoT, e.g, cybersecurity, and the economic viability of the new value proposition. The framework proposed in this work intends to manage these challenges in the design process of Smart PSS solutions.

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