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Smart PSS modelling language for value offer prototyping: A design case study in the field of heating appliance offers

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ABSTRACT

The recent convergence between two industrial transitions towards digitalization on the one side and servitization on the other side led to the new business strategies of digital servitization and smart PSS delivery. While inheriting from the previous scientific literature on PSS, because of the multiple impacts of digitalization in the overall system, the processes of ensuring the design and engineering of smart PSS solutions poses new challenges. This research addresses the specific needs to develop conceptual prototypes of smart PSS value offers, at early stages of the design process. The paper presents the development and experimentation of a modelling language and its associated modelling toolkit (sPS^{2}Modeller). The application case study addresses the design of a smart PSS in the field of heating appliances, developed in collaboration with the company elm.leblanc, Bosch Group – France.

1. Introduction

Following the rather recent emergence, in industrial companies, of digital servitization strategies (Pirola et al., 2020; Paschou et al., 2020) at the convergence between digitalization and servitization, the notion of smart PSS is becoming an important trend of research (Zheng et al., 2019; Liu et al., 2018). The challenge is to integrate both the notion of smartness (Romero et al., 2020) and the notion of product-service-systems (Tukker, 2004; Baines et al., 2009). Catalyzing this strategy, the European commission pushes forward the concept of digital innovations, notably for Small and Medium Enterprises (Sassanelli and Terzi, 2022). The notion of smart PSS was recently defined as “digital-enabled holistic solution, developed and supplied within an ecosystem, which provides economic and sustainable value to a main customer and complementary stakeholders, by integrating into a unique offer connected products together with data-driven services delivered all along the solution’s lifecycle, supported by physical and digital infrastructures” (Boucher at al, 2022). This definition emphasizes the systemic characteristics of smart PSS: emerging from interactions within a business ecosystem, they are supported by multi-actor collaborative value networks (Sjödin et al., 2020; Lamperti et al., 2023) and use digital infrastructures and solutions to provide added-value along their whole life-cycles (Cenamor et al., 2017). This systemic complexity put smart PSS at the convergence of many complementary research works in design sciences (e.g. Hagen et al., 2018; Zou et al., 2018; Andriankaja et al., 2018).

In this perspective, the current paper puts the focus on early design phases, where the main question is to conceptualize and design the smart PSS ‘Value Proposition’. The research results presented in the following sections address specifically this phase of value proposition conceptualization. Largely influenced by the design thinking approach (Osterwalder et al., 2010), many authors have contributed to push forward the pre-eminence of Value Proposition building processes, for smart PSS design (Orellano et al., 2021; Da Costa Fernandes et al., 2020; Sjödin et al., 2020; Chang et al., 2019). Some of them propose design frameworks in this perspective. For instance, with a value co-creation process for Smart PSS development based on the four design steps: co-exist, co-design, co-implement, and co-evaluate (Liu et al., 2018). However, Murillo-Coba et al. (2023a) show that the full process of value proposition design still lacks of consistent prototyping tools. Such tools could support a shared visualization of the value proposition components, a shared knowledge on the design information and knowledge, and an explicit visualization of the value flow among the stakeholders which could also open additional opportunities to assess value exchanges. The research presented in this article, aims at answering these needs. Our proposal is to develop a conceptual language, dedicated at visualizing and prototyping smart PSS value propositions. The utilization of its implemented version, called SPS^{2}Modeller, is illustrated in the

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paper. Among various categories of prototypes, as presented in (Murillo-Coba, 2022), the Value Proposition models created with SPS^{2}Modeller can be considered as 'conceptual prototypes', i.e. structured and graphical representations of design knowledge, shared among the multiple stakeholders and used as a support to ensure design analysis and convergence. This specific type of prototypes intends to fill the lack of supporting tools for the early design conceptualization phase (Solem et al., 2021; Fialho et al., 2022).

The paper first presents the research methodology followed for the creation of this new modelling language (Section 2). Section 3 presents the literature on smart PSS modelling and prototyping in the context of design frameworks. Then, Section 4 describes the results of this work, starting with the meta-modelling procedure followed in the research, then the formalization of smart PSS meta-model proposed to support value proposition building and, finally, the implementation of the operational modelling language itself. An industrial application in the field of heat production appliances is developed in Section 5, used as an experimentation step of the applicability of the modelling language. The added value, limits and perspectives of this research are discussed in Section 6.

2. Related works: prototyping tools to support smart PSS early design

Valencia Cardona et al. (2014) identified the clear communication of design goals among project stakeholders as one of the key challenges for Smart PSS designers. This difficulty is associated with the fact that a Smart PSS offering is a bundle of products together with physical and digital services. Consequently, at early design time, the need to visualize and configure the interactions among the distinct elements of the value proposition as well as the interrelations among the actors of the Smart PSS value delivery network. In product development, designers visualize the appearance of the design object through computer-aided virtualization tools (digital mockups of the physical products). Following this logic, scholars have called for the development of visualization approaches to make tangible all components of a value proposition in PSS and Smart PSS design (Exner et al., 2014; Valencia Cardona et al., 2014; Trevisan and Brissaud, 2017; Hagen et al., 2018; Ilg et al., 2018). We address this issue in the two following sections, first with general insights on needs and requirements for modelling or prototyping tasks in smart PSS early design (Section 2.1), then with a more specific focus concerning existing conceptual modelling language oriented towards PSS or smart PSS conceptualization phase (Section 2.2).

2.1. Modelling and prototyping requirements for early-design of smart PSS

Previous to the emergence of smart PSS, the latest decade has generated a deep and inspiring background of knowledge on PSS design processes and methodologies. Several contributions have progressively mixed modelling and decision-support tools to provide integrated methodologies: for instance, the premising methodology by Hara et al. (2009); then, more recently the Service Engineering Methodology (SEEM) by Pezzotta et al. (2016); a three steps PSS design methodology by Fargnoli et al. (2019), and Haber et al. (2020); the Product-Service System Lean Design Methodology (PSSLDM) by Pezzotta et al. (2018), or the Extended Functional Analysis (EFA) approach by Andriankaja et al. (2018). One of the more recent methodology dedicated to PSS is the so-called Guru Methodology (Sassanelli et al., 2019), which intends to provide technical direction and design ideas as part of PSS design processes. All these contributions, oriented on servitization, provide important advances on the overall design process and notably on the potential approaches to ensure a good integration among service versus process design.

Beyond the servitization strategies, Pirola et. al (2020) show that the emergence of digital servitization and smart PSS concepts leads design methods to a new level of complexity for system design (Gaiardelli et al., 2023). This leads to a complementary trend of research in design, focusing on the specificities of smart PSS, for instance with the contributions from (Liu and Ming, 2019; Chang et al., 2019; Lee, and Sjödin et al., 2019, 2020). The smart PSS design process is notably characterized by the following key factors:

1. *Level of integration of actors and design dimensions.* With regards to usual design integration, smart PSS still increases integration requirements by the necessity to embed three conceptual areas: products, services, and value networks (Andriankaja et al., 2018). Digital solutions open the opportunity to manage this integration at each step of the full solution's lifecycle, with imbrication among multiple product- and service-lifecycles. This leads to consider, from the early design stages, the potential to embed with the smart PSS offer several interoperable Decision-Support-Systems able to provide consistent added-value at the various stages of the lifecycles. Such added-value components are addressed not only to the final user, but potentially to other stakeholders, which are actors of the value delivery network and who could be considered as intermediary beneficiary of some parts of the full PSS offer and solution.
2. *Smartness considered at all levels of design.* To support this interlacing of product and service lifecycles, interoperable digital capabilities of the overall solution become crucial. Smartness should be considered at all stages of the design process, starting from early design phases (Gaiardelli et al., 2023; Pirola et al., 2020; Zheng et al., 2019), including the phases of value expectation capture and service ideation. Smartness should be considered not only from a technical point of view, but also through its economic performance impacts (it can contribute to the economic model of various actors), as well as from a risk anticipation point of view (Murillo-Coba et al., 2023b; Parida et al., 2019). The capacity to integrate risk anticipation at design time becomes a major issue, with smartness risks of various nature: technical risks of interoperability; data risks of accessibility, availability and reliability; network risks of cyber security; economical risks of information dependency, etc. Risk management should be fully included in the design framework itself.
3. *Crucial importance of value-driven design.* Value Network design requires innovative methodologies oriented on value capture, and value network configuration, as well as economic model calibration, inducing a transformation of firms' internal design skills. Most PSS design methods (e.g. Trevisan and Brissaud, 2017; Lee et al., 2019; Orellano et al., 2021) already include today's Design Thinking approaches to capture and analyze value expectations from the customers, while considering multiple value dimensions (not only economical but also ecological, societal, information or relational aspects). However, beyond value expectations capture and alignment, complementary issues remained to be addressed notably (i) how to prototype and design value delivery networks and (ii) how to calibrate value-sharing mechanisms among stakeholders at design time. Such challenges also contribute to risk management underlined above, with the aim to establish win-win conditions for all actors involved in the Smart PSS delivery.

To address, at the early design stage, these requirements of integration, smartness and value-oriented design, a promising approach relies on an extended notion of 'prototyping'. This approach consists in extending the notion of product prototype already used in usual design towards a larger vision of value-system prototyping, which includes different types of prototypes. We distinguish between prototyping using qualitative and quantitative methods. The former outlines creative ideas by using types of prototypes such as mock-ups, sketches, charts, storyboards, service blueprinting, business model canvas, minimum viable product (MVP), minimum viable ecosystem (MVE), and role-playing (Lewrick et al., 2018). These qualitative prototypes can typically support early design steps. The latter supports the elaboration of the business case by using quantitative methods and tools, with the aim to predict profit generation derived from the commercialization of the designed offering. Examples of methods employed to support this economic performance evaluation are cost-benefit analysis and computer simulation (Osterwalder and Pigneur, 2010; Boucher et al., 2019).

In the PSS design context, Ilg et al. (2018) defined the characteristics of a PSS prototype based on the findings of Exner et al. (2015). A PSS prototype should enable the visualization of the PSS offering, including all its components and no single components separately. Notwithstanding, the development of a single PSS prototype is not feasible according to Ilg et al. (2018). Instead, these authors recommend the utilization of multiple variations of prototypes depending on the needs of each design phase. Exner et al. (2016) identified IDEF0 modelling, use cases, system maps, virtual prototypes, block diagrams and meta-modelling as alternative prototyping techniques employed in PSS design, aimed at visualizing the components of the PSS solution.

During early design steps, PSS prototyping has two main roles. First, these prototypes should facilitate the assessment of the Smart PSS value proposition's customer desirability. Second, PSS prototypes are used to enable the validation steps in the design process. These validation activities involve carrying out tests to determine whether the PSS concept under construction meets the PSS solution requirements (Exner et al., 2014), for instance, the feasibility of the PSS delivery network. Dewit et al. (2021) stressed this pivotal role of prototyping in the recurring validation activities during the PSS early design phase. In this perspective, next section provides complementary insights on conceptual modelling languages to support PSS prototyping.

2.2. Smart PSS conceptual modelling languages

The use of prototypes of low degree of detail, in the early design phase, such as sketches, storyboards, and wireframes, is suggested by Lewrick et al. (2018). In the scope of this work, the design object is the system associated with the Smart PSS offering. In this regard, graphical representations have been used in PSS design to support the value proposition design and the value network configuration (Table 1). Conceptual modelling is one of the graphical representation approaches employed in traditional PSS design to visualize the service-based offering as a system (Idrissi et al., 2017; Pirayesh et al., 2018).

Mylopoulos (1992) defined conceptual modelling as "*the activity of formally describing some aspects of the physical and social world around us, for purposes of understanding and communication*". Thus, conceptual modelling has been applied with the purpose of making abstractions of the system associated with the PSS offer, by using models. A model is "*a reduced representation of some system that highlights the properties of interest from a given viewpoint*" according to Selic (2003).

In order to create a model, practitioners use a modelling language. Da Silva (2015) defines a modelling language as "*a set of possible models that are conformant with the modelling language abstract syntax, represented by one or more concrete syntaxes and that satisfy a given semantics*". The abstract syntax mentioned in this definition is also known as meta-model or model of a model. A meta-model is aimed at defining the structure of a modelling language (i.e., the objects represented in the model and the relationships among the models). The first meta-models devoted to PSS design were presented by Abramovici et al. (2009) and Müller et al. (2009). These first meta-modelling approaches paved the way for other scholars to propose modelling languages adapted to PSS design's specifications (Idrissi et al., 2017; Maleki et al., 2018a).

Karagiannis et al. (2022) argue that a meta-modelling approach is suitable to operationalize Smart PSS prototyping. These authors report that this approach makes the design space adjustable to the stakeholders' ever-changing needs. Thus, the meta-modelling approach can be considered as an agile prototype. As for PSS agile prototyping tools, Medini and Boucher (2019) and Pirola et al. (2022) present tailored meta-models for PSS design and computer-aided tools implementing their meta-models to create digital models.

Table 1
Characterization of the Smart PSS conceptual modelling languages.

Emerging factor in Smart PSS design	Level of integration of actors and design dimensions	Smartness considered at all levels of design	Value-driven design
Buchman et al. (2016)	**Partially addressed:** Details the structure of the product but it does not explicitly specify the services included in the Smart PSS offering. The roles and entities of the business environment are modeled.	**Partially addressed:** Sensors and actuators are considered. Defects related to processes, skills, and organizational roles are integrated in the meta-model.	**Not addressed:** Value exchanges among actors and scenarios to commercialize the Smart PSS offering are not included.
Maleki et al. (2018b)	**Weakly integrated:** Products and services included in the Smart PSS offering are not detailed. The actors involved in Smart PSS value creation and value delivery are not included.	**Partially integrated:** Risk evaluation integrated in lifecycle stages. Operation-related and collaboration-related events with a negative impact considered. No mention of economic viability-related risks.	**Not addressed:** Absence of economic performance indicators, actors' value expectations, and value delivery scenarios.
Lüttenberg (2020)	**Partially integrated:** Integrates two properties of smart products: sensors and actuators. No mention of periphery products to deliver the Smart PSS solution. Includes roles of actors only from the digital platform perspective: platform owner, producer, service provider, and service customer. The meta-model assigns technical design decisions to actors. It does not consider the co-existence of smart services and physical services.	**Partially integrated:** No explicit mention of risks for Smart PSS delivery. Considers data generated by smart products and smart services enabled by these smart products. Integrates three types of platforms and three different interfaces.	**Not addressed:** No mention of performance indicators to evaluate the Smart PSS delivery networks or the value exchanges among the actors. No mention of actors' value expectations. No mention of the economic models to commercialize the Smart PSS offering.
Kaiser et al. (2021)	**Weakly addressed:** Participating entities and digital ecosystem actor roles are described. However, there is no specification of the services included in the Smart PSS. The meta-model is aimed at the automotive industry.	**Partially addressed:** Types of data needed in the value creation process are integrated.	**Weakly addressed:** Oriented on value creation. But, no mention to value expectations, or value exchanges among the digital ecosystem actors.

Now, more specifically focusing on Smart PSS design, to the knowledge of the authors, the literature puts forth four meta-modelling approaches. In Table 1, we position these four meta-models with regards to the three key smart PSS design requirements identified previously (i) Level of integration of actors and design dimensions; (ii) Smartness considered at all levels of design, (iii) Value-driven design. Buchmann (2016) present a meta-model aimed at enabling the creation of ten different digital models. These models are created by using a computer-based tool. The models generated by this tool are called: business process, interaction process, orchestration, business entities, value structure, machine structure, location structure, interaction elements (Mobile IT support), resource pool, and information space. Maleki et al. (2018b) report two meta-models aimed at supporting the definition of the PSS lifecycle and the PSS business processes. These meta-models assist Smart PSS designers to differentiate between the elements that are part of the system of interest (e.g., the service processing activities) and those that belong to the enabling systems (e.g., organizational capabilities). Lüttenberg (2020) proposes a meta-model for Smart PSS design that includes platform-based characteristics. Kaiser et al. (2021) introduce a meta-model that details a conceptual multi-actor model for value creation. This meta-model is aimed at the design of vehicle data-driven services. As stressed in Table 1, these Smart PSS meta-modelling approaches do not cover concurrently the three key Smart PSS design factors described in Section 3.1.

2.3. Positioning of the contribution

The contribution of this paper aims at supporting early design tasks for smart PSS. The previous state of the art showed the importance to configure the key elements of Value Offers, including value expectations, value proposition, but also value networks (Parida et al., 2019; Cimini et al., 2021; Rapaccini and Adrodegari, 2022). The recent increase of research works on Smart PSS opens a new research orientation concerning the applicability of prototyping techniques to support the design process. Scholars have argued that the inclusion of a prototyping approach is paramount for the successful design of Smart PSS offerings (Solem et al., 2021; Fialho et al., 2022). However, literature in Smart PSS lacks prototyping approaches addressing the key characteristics of Smart PSS design out forth in Section 2.1. Table 1 clearly emphasize that the smart PSS requirements are not fully covered by existing meta-models and notably that the 'Value dimension' is poorly treated. The current contribution intends to answer these value proposition prototyping needs.

In this paper, we adopt the definition of prototyping provided by Osterwalder and Pigneur (2010) as "*a tool that makes abstract concepts tangible and facilitates the exploration of new ideas*". In this perspective, the paper proposes to use the scientific background on conceptual modelling languages presented in Section 2.2 in order to develop a new specific modelling language dedicated to support smart PSS early design. In this perspective, the research methodology includes the specification of a new meta-model dedicated to smart PSS Early-Design, then the development of the associated modelling language which make possible to implement of a prototyping tool to be used by industrial designers.

3. Research method

The research methodology used to lead this research work follows a collaborative action research method. Globally the research process synthesized in Fig. 1 follows the principles of the general Design Research Methodology (DRM) as defined in (Blessing and Chakrabarti, 2009) and consistent with the research process formalized previously by Peffers et al. (2006). The logic of the four methodological steps of Fig. 1, is to structure rigorously the scientific production of the new modelling language and expected prototyping tool; additionally, Fig. 1 clearly underlines the collaborative dimension of the research, with the implication of the industrial partners from step 1 to step 4.

The collaborative research between academics and industrialists was developed in the context of a collaborative PhD thesis between (i) Mines Saint-Etienne LIMOS research group dedicated to Servitization and (ii) the industrial company elm.leblanc – Bosch Group France. This type of collaborative PhD makes the PhD student directly hired by the company, with large periods of time directly on industrial site, to facilitate a concrete integration of the student with the company culture and working methods. This industrial integration of the PhD Student facilitates an action research approach following a collaborative and iterative

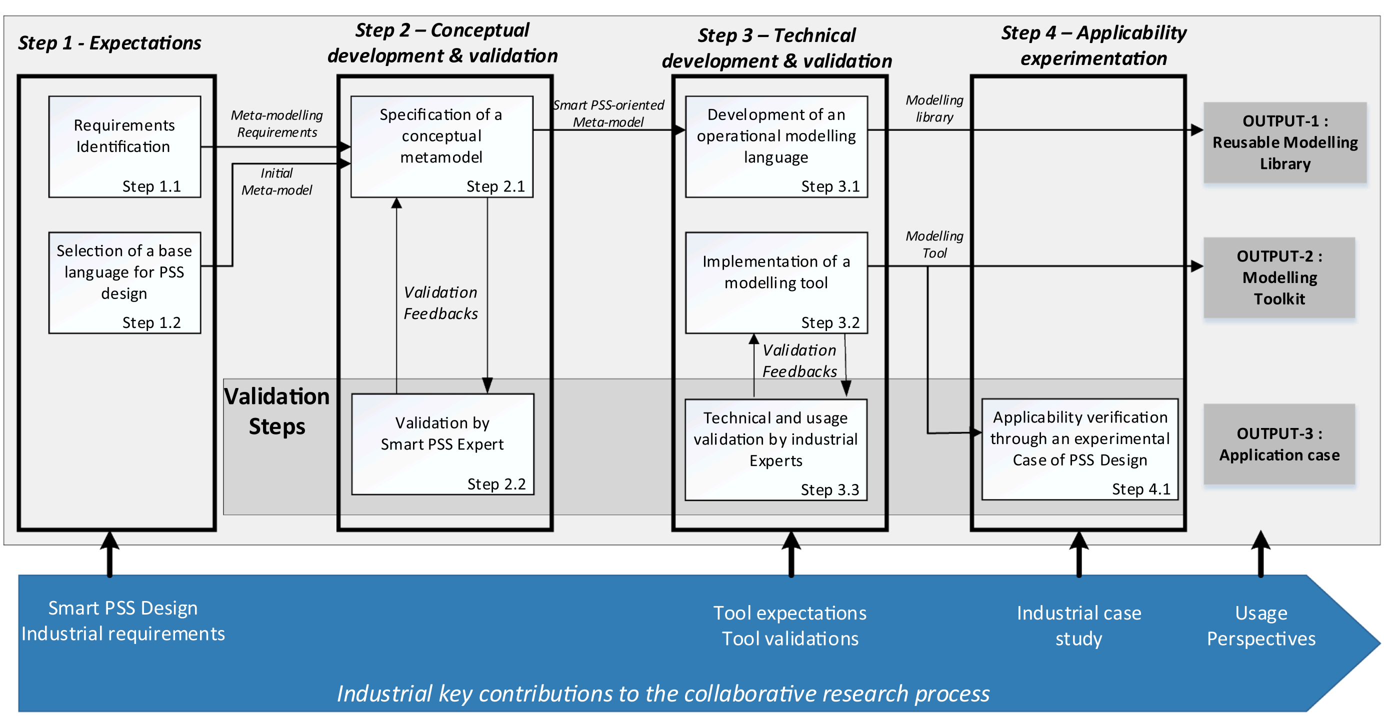

Fig. 1. Research methodology.

methodology as emphasized by Ellström (2007): starting from the elements available in the state of the art and current state of industrial practices, the authors used several steps of collaboration incrementally built and validated a new research output, which is expected to bring some changes in industrial practices both by the knowledge added-value of the building process and by the final output itself. As clarified by Fig. 1, the main collaboration steps include the identification of industrial requirements for smart PSS design (step 1.1), the validation of the Modelling toolkit proposal (step 3.3), the deployment of a validation application case (step 4.1) with specific formalization of the collaborative interactions for each of these steps.

3.1. Step 1 - Expectations

Step 1 of the research process ('Expectations') is dedicated to study the requirements for smart PSS conceptual modelling is based both on an academic state of the art and on close interaction with industrialists to capture the needs and expectations. Step 1.1, the capture of industrial design requirements, was based on (i) a period of internal training of the PhD student on the industrial design methods of the company and (ii) on internal interactive seminars to interview designers on their personal needs in the perspective of smart PSS design. Then step 1.2 was based on literature review to identify the key scientific contributions on smart PSS modelling methods and techniques.

This analysis provided key conclusions on the requirements for smart PSS design. The scientific requirements are directly linked to the orientations mentioned in Section 3 concerning (i) multi-actor integration, (ii) consideration of smartness and associated risks at all steps of the design and (iii) crucial importance of value-oriented design. Smart PSS modelling languages should support the intellectual effort required from the design team of shifting, during the early design process, from a system level mindset (considering the Smart PSS offering as a whole) to the system details (Valencia Cardona, 2017). They should also support multi-actor design decision-making at various levels: (i) at a strategical level, to help defining the diversity of economic models the Smart PSS offering could be based on; (ii) at a tactical level, regarding the tactical sets identified by Reim et al. (2015), namely contracts, marketing, network, product and service design and sustainability; (iii) then from a risk perspective, to help exploring the Smart PSS offering's desirability, feasibility, and viability during the early design phase, an angle that remains unexplored in Smart PSS literature. From an ergonomic point of view, modelling languages should propose graphical representation, easily understandable by very distinct actors with different skills across the design teams and stakeholders, to facilitate multiple interactions during iterative design loops (Murillo-Coba et al., 2023a) and to help identifying collaboratively the diverse sources of innovation risks.

Industrial requirements are quite converging with these literature insights, notably through the notion of value: the company elm.leblanc is profoundly involved in digital servitization transition, leading to a cultural transition of designer competencies towards value design. Thus, the company confirms the needs of further visualization and prototyping tools to support the design of value systems. Furthermore, business remains the key driver for the company: the necessity to validate the economic viability of the smart PSS offer is identified as a key objective. In the same perspective, there is a strong industrial need to identify and assess key innovation risks. From an ergonomic point of view, additionally to the requirement to support interaction among multi-cultural design actors in order to boost the quality of cross-functional exchanges, elm.leblanc underlines a specific need to integrate the principles of agile design approaches (Table 2).

Complementary to this requirement analysis, step 1.2 had the objective to make possible the re-use of previous scientific developments on smart PSS modelling languages, with a strategy of incremental modelling language definition, so as to avoid starting from scratch. This result is the input of step 2.

Table 2
Key requirements for smart PSS modelling languages.

	Scientific literature gaps	Key industrial needs
Content requirements	Visualization of value dimensions, flow and delivery system. Consider smartness dimension along the whole design process, starting with expectation capture. Identification and management of key innovation risks, at early design stages. Provide decision-making help for designers at strategic and tactical levels.	A methodological structuration of value oriented design and sharing of pieces of information on the value system, among all designers. A support for identification and analysis of smart services opportunities Anticipation of different types of Smart PSS innovation risks. Demonstration of the economic viability of smart PSS value offer.
Ergonomic requirements	A single conceptual modelling environment to gather and share the main design knowledge generated along all steps of design. Support easily multi-skills design actors' interactions	Support interactions among different kind of designers. Work with agile design methods, based on design iterations and prototypes, even at early design. Articulate modelling tools, with other design thinking and risk oriented design tools in use at elm. Articulation between qualitative and quantitative prototypes (economic simulation).

3.2. Step 2 – Conceptual development and validation

The second phase of the methodology is dedicated to the definition of a new modelling language for smart PSS. Step 2.1 is dedicated to the formalization of a conceptual meta-model, which re-uses existing advances resulting from literature review and proposes new advances to answer the expectations. The meta-modelling procedure was based on incremental model specification: as a result of the state of the art from Step 1.2, the initial PSS-oriented modelling language published by (Medini and Boucher, 2019) has been selected as the starting basis to answer the overall requirements. This initial modelling language addresses PSS design from a business value perspective.

Starting from this initial Input, the authors followed a usual meta-modelling procedure (Karagiannis et al., 2016) which consists in extending and generalizing the initial modelling concepts, to cover the overall set of modelling expectations resulting from step 1. The meta-modelling procedure specifies the modelling views, modelling objects, and attributes of the objects to support the various needs made explicit through the preliminary requirement analysis. The main output of this step 2.1 is the meta-model itself, specifying formally (using UML formalism) all modelling useful views, objects and attributes. This meta-model then goes through the conceptual validation step 2.2, executed by well-recognized academic experts in the field of smart PSS: this validation checks the overall consistency of the model and its pertinence concerning the requirements.

The key output of step 2, the meta-model proposed to support smart PSS design, is presented in Section 4.1.

3.3. Step 3 – Technical development and validation

Steps 3 covers the transformation and implementation of this meta-model into an operational modelling language (Step 3.1). In parallel, the objective is also to develop a computer-based Modelling Tool in order to ensure the pragmatic utilization of this new smart PSS dedicated language (Step 3.2). The ADOxx metamodeling platform was selected to support the developments. This technical meta-modelling environment and platform, supported by the OMiLAB Community (Karagiannis et al., 2016), offers an integrated software suite to derive and implement new modelling languages, from a high level generic meta-model. The platform presents the strong advantage to follow open software principles and to provide a powerful development environment, supporting the implementation of both new modelling libraries and toolkits: the meta-modelling approaches of ADOxx offers a real benefit to facilitate these developments. Following the procedure above, the technical developments follow a user-oriented validation (Step 3.3): facilitated by the integration of the PhD research within the industrial environment, interactive workshops are organized with key potential users of the tool (industrial designers of smart PSS solutions). The feedbacks are used, when necessary, to adapt some elements of the meta-model or, more pragmatically, to improve the ergonomics of the tool.

The application of this meta-modelling procedure led to the outputs presented in Section 4.2.

3.4. Step 4 – Applicability experimentation

The last phase consists in an experimental verification of the industrial usability of the approach. The objective is to test the applicability of

Table 3
Brief description of the ten modelling views.

Type of View	Modelling view	Objective of the modelling view	Key modelling constructs and pieces of design information stored in their attributes
Contextual view	Business Ecosystem Organization	Model of the contextual Ecosystem where a given smart PSS is developed: key stakeholders, their interactions and key expectations Model of potential actors for the value network, with their capabilities and resources mobilized to take charge key activities contributing to Smart PSS delivery. Identification of operational risks assumed by these actors in this context.	• *Economic actors* • *Non-economic actors* • *External actors*: contribution to value creation, perceived value added, strategic issues, providing costs structure, providing costs. • *Human resources*: professional skills, • *Physical resources*: energy & consumable cost structure, actual & theoretical capacity. • *Risks*: Key risks assumed by the actors, which could influence smart PSS value network.
Structural view	Product	Representation of the overall structure of the core products integrated into the Smart PSS offering, the periphery products that support the solution delivery, and the connectivity devices.	• *Core product*: customer and other stakeholders' requirements, differentiation factors, lifetime, mean time between failures (MTBF), mean time to repair (MTTR), downtime, energy cost structure, consumables, depreciation, maximum margin. • *Periphery product*: type, operating and maintenance instructions.
	Service	Structure description of a catalogue of digital and non-digital services that may be delivered throughout the whole Smart PSS lifecycle steps: configuration, installation, maintenance, upgrade, uninstallation/ final disposal.	• *Service:* Scope, functional units, gain creators/pain relievers for all value dimensions, service cost structure, maximum pricing margin. • *Digital service*: Scope, payment periodicity, data required, data processing and use, capability required, gain creators/pain relievers for all value dimensions, functional units, service cost structure, maximum pricing margin.
	Activity	Model of the activities and processes required to deliver the Smart PSS offering. Activities are differentiated by their scope: logistic, design, front office, back office, and use activities.	• *Activities*: value creation activity duration, value creation activity cost, activity cost structure. • *Macro-activities (composed by a set of activities)*: objective, distinctive technological value added, service activities excluded from the agreement, frequency of the macro-activity, circumstances that trigger the performance of the macro-activity, value creation activity duration. • *Service (additional attribute)*: scope of the service, periodicity, *Product (additional attribute)*: expected upgrades.
	Offer	Model of the combination of products and services integrated within a specific value offer and associated to an overview of the contracts between the Smart PSS provider and customers.	Offer: remedies, terms of agreement. *Contract model*: Type of contract (product-, use- or result- oriented), contract duration, terms of payment, selling prices. *Contractor*: customer obligations. *Smart PSS provider*: limitations in reliability.
Dynamic Views	Demand	Description of the potential market, through a set of customer categories (characterized by a commercial and a usage profile) associated with quantitative information on the demand.	*Customer class*: business sector, expected contribution to turnover, contribution to total margin. *Customer profile*: commercial profile, use profile, main customer jobs/ gain & pain points. *Demand* (associated with a customer class): description, overall estimated demand, demand per period, competitors. *Customer/end user*: description, customer jobs, gain and pain points.
	Performance	Hierarchical description of potential performance indicators on which the Smart PSS offering can be assessed, depending on the point of view of some actor of the value network.	*Performance indicator:* name, unit, formula, value.
	Scenario	Model of alternative Smart PSS delivery networks, displaying the actors' roles, capabilities and KPIs for the Smart PSS offering commercialization.	*Role*: description, service fees, payment frequency, handling of non-payment. *Performer*: obligations of the performer, penalties applied if the performer is not able to carry out the service, penalties applied if the service contract is terminated, assigned role. *Offer:* reference to offer view
	Value Network	It displays the alternative configurations of the Smart PSS value networks associated to the *Scenarios* and identifies the various value exchanges as well as data and information flows among these actors.	*Stakeholder (Classified in five categories):* Manufacturer, physical service provider, digital service-related providers, influencers, customer/end-user. *Tangible value objects*: description, products. *Intangible and mixed value objects*: description, physical services, digital services. *Object relation 'provides value object'*: value transaction dimension (financial transaction, environmental, social, functional, relational). *Object relation 'Data/information flow'*: description of data/information, source of data/information.

the modelling method, language and tool proposed throughout a real industrial project of smart PSS design, to get feedback on potential difficulties of usability and to verify the capabilities with regards to the expectations. Such a verification is much more limited than a full qualitative validation process, which remains out of the scope of the current research (see Section 7 on perspectives). The case study, applied to the heating industry in collaboration with elm.leblanc – Bosch France, is presented in Section 5.

4. Development of the modelling Library (Output-1) and modelling toolkit (Output2)

4.1. Smart PSS design oriented Meta-Model

The conceptual model structures all modelling constructs useful to build the required design-oriented models of a smart PSS, through a set of so-called '*modelling views*'. Each modelling view can be understood as a subset of the overall conceptual model, which will facilitate the usability of the overall meta-model after implementation. Thus, a modelling view gathers a limited set of modelling constructs, corresponding to a specific type of model proposed to help the multi-actor design process. After implementation, during a concrete smart PSS project utilization, these modelling views will be progressively utilized along the design process to gather the key pieces of information on design specifications and decisions.

The iterative meta-modelling procedure led to define ten modelling views briefly synthesized in Table 3. The ten modelling views constituting the meta-model are distributed among three complementary types of view according to their utilization during the design process: the Contextual, Structural and Dynamic views, further detailed below.

The Contextual views (Fig. 2) are dedicated to represent key pieces of information which does not directly define the smart PSS nor the way to deliver it, but which are necessary to apprehend consistently the design context. The *Business Ecosystem view* consists in a mapping of the key actors of the economic environment where the smart PSS is expected to be delivered. The objective is to identify exhaustively the stakeholders of the smart PSS Business Ecosystem: economic and non-economic actors are distinguished and their existing interactions and financial exchanges are mapped. This business Ecosystem view is used at the very beginning of the Design process, in an initial step of context awareness. Then, the second Contextual view is the *Organization view*. This view is used later during the design process, at a time when the potential actors required to constitute the smart PSS delivery network have to be defined. The objective of this view is to identify and characterize an open set of potential organizational actors (e.g. companies) which could contribute to the implementation of the delivery network. The organizational actors are described in terms of key activities they can take in charge, depending on their collective competencies. Thus, this view is preparing the information necessary for later selecting partners within the value network.

Then come four Structural views (Fig. 3). These views gather key pieces of information on the structural components of the smart PSS. Key design pieces of knowledge are progressively gathered in these four

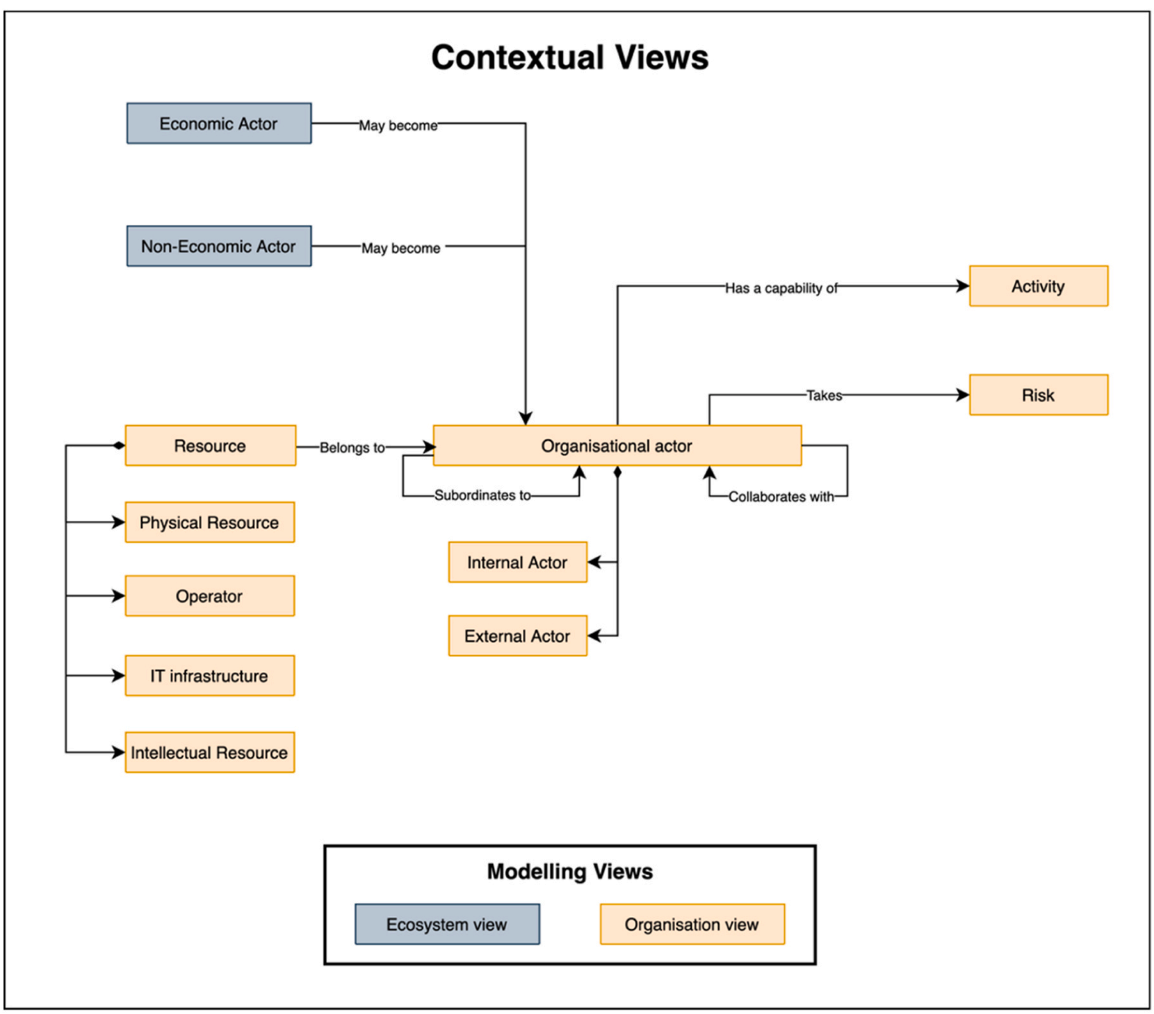

Fig. 2. Contextual views.

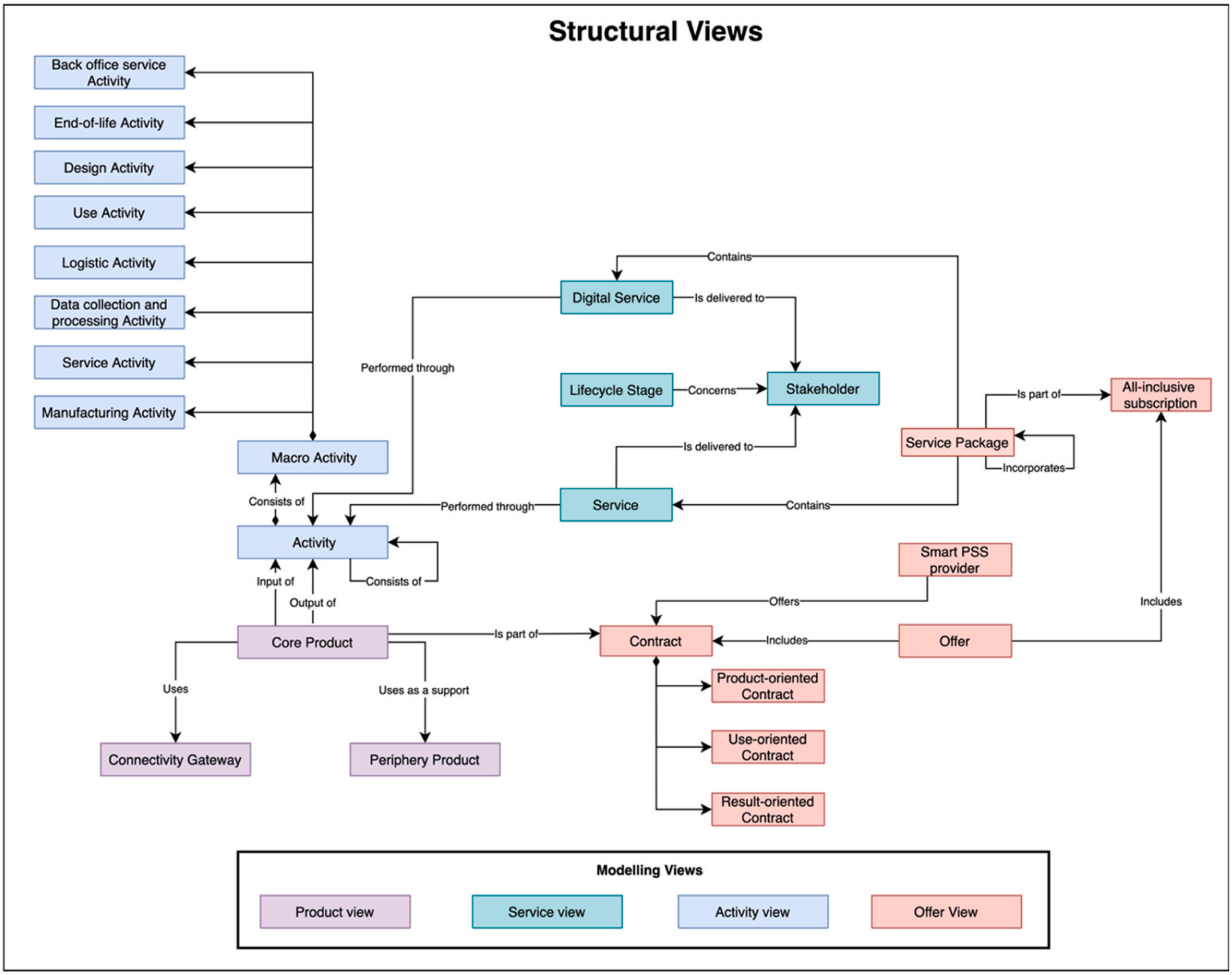

Fig. 3. Structural views.

views, concerning the tangible components (products), the intangible ones (services), the operations required to deliver both products and services (activities) and the combination of tangible and intangible components in smart PSS offerings (offers). As described in Table 3 the conceptual models of the three first views respectively represent: (1) the key structural sub-systems of the products included in a smart PSS offer under design (*Product View*); (2) a structured catalog of potential services which could be implemented along the product lifecycle and which are defined by the designers during the design process (*Service View*); (3) and the key industrial- or service- oriented activities required to deliver the whole value expected from the smart PSS (*Activity View*). These pieces of information will be re-used at different stages of the design process, for instance to configure value delivering scenarios and networks, then to assess their performance. The fourth structural view, the *Offer View*, is used for a first structured definition of the smart PSS value offering. This conceptual model combines product components, with services (of the service catalog) organized within specific service packages, associated to a first specification of the type of commercialization contract (with a selection among three main types of contract: product-use- or result-oriented contracts). During a design process, the designers can model several instantiations of the Offer View. Each instantiation represents a specific value offer, generally corresponding to a particular category of customers, and thus value expectations.

Finally, the four so-called Dynamic Views aim at specifying the process dynamics of the smart PSS under design (Fig. 4). Through the *Demand View,* the overall market targeted by the smart PSS is divided into several customer categories characterized by distinct value expectations. Each customer class is also described with quantitative information of the market estimation (and potential evolution) which can be used during the design process for some quantitative assessments. The *Performance View* supports the hierarchical description of performance indicators, selected by the designers for the comparative performance evaluation of alternative smart PSS scenarios. These scenarios are defined in another view: the *Scenario View*. This view is quite important during the design process, since it is used to configure and characterize a delivery network, i.e. a dedicated way to deliver a specific PSS offer. A delivery network is specified by the targeted offer (defined with the *Offer View*) and by a set of organizational roles taking in charge activities (defined with the A*ctivity View),* which can then be assigned to organizational actors (defined with the *Organizational View)* and assessed via dedicated performance indicators (defined with the *Performance View)*. Of course, several alternative *Scenario Views* are generally created during the design, corresponding to alternative channels to deliver the smart PSS offer, which can also typically correspond to alternative *Offer Views*. However, the *Scenario View* is not sufficient to represent all dimensions of the value exchanged among the network actors, which can embed many forms of value linked not only to product exchanges, but also to information flows and data valorization, service-oriented

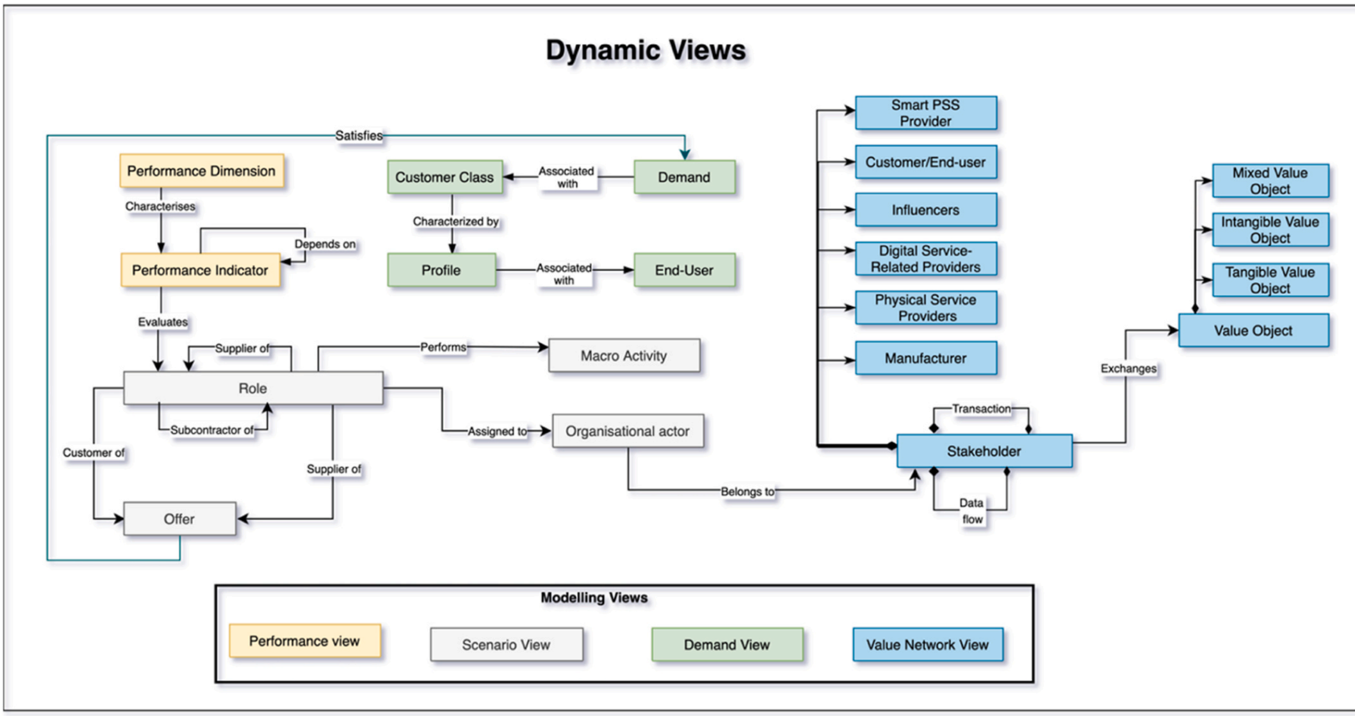

Fig. 4. Structural views.

lifecycle management, or brand image, etc. Thus, complementarily, each delivery network is also associated to a *Value Network View*, which defines the different types of value and information exchanges among all the participants.

The ten conceptual modelling views defined above are integrated in an overall meta-model, presented in Fig. 5. This meta-model leads to the development of the modelling Library and Toolkit described in the next section.

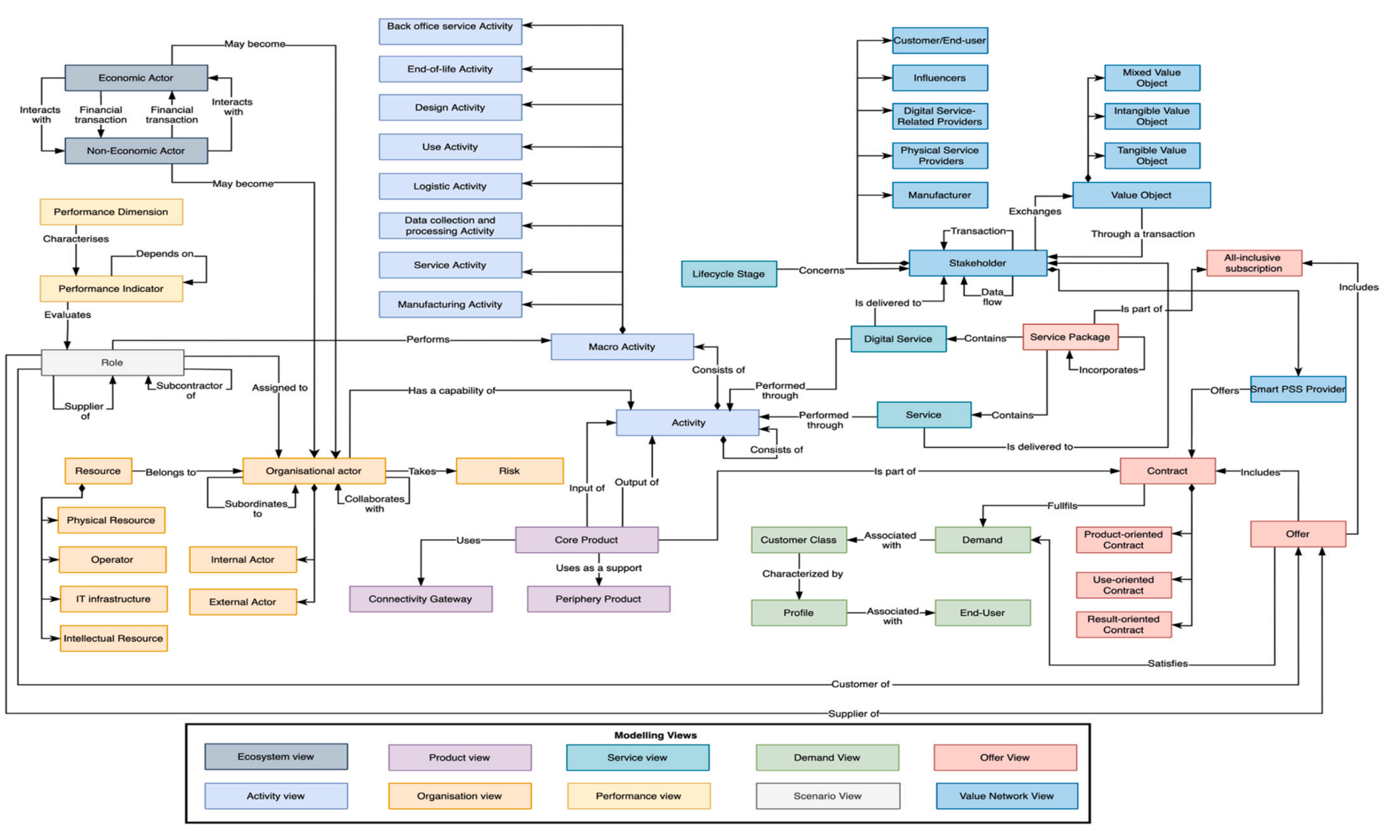

Fig. 5. Resulting Smart PSS Metamodel.

4.2. Modelling library and toolkit

As introduced in Section 3.3, the ADOxx meta-modelling platform was selected for the technical implementation of the conceptual meta-model. Through these developments the conceptual meta-model is transformed into a computer Modelling Library, usable by the final users as a Modelling Language. Formally, each *Modelling View* defined in the conceptual model corresponds to so called '*Model Type*' within the implemented Modelling Library. All Model Types gather a set of '*modelling object*', each of them corresponding to a specific '*modelling construct*' in the meta-model.

The full set of conceptual modelling constructs are in fact transformed into two main types of modelling objects, called 'objects' and 'relationships'. The 'object classes' are used to model the key elements of any Model Type. For instance, the object class 'Economic actor' is used to characterize a socio-economic actor as part of the Model Type 'Business Ecosystem' of the modelling language corresponding to the Business Ecosystem Modelling View in Table 1; and the relationship class 'Interacts with' is used in the same Model Type to represent an existing interaction among stakeholders. Any modelling objects is characterized by a set of descriptive attributes. Among these attributes, two important generic attributes defined for every modelling object, are the object's *graphical representation* (each object or relationship can be accessed through a graphical icon) and its *notebook* (i.e., a public interface of the object, used to display or collect data corresponding to the values of the object's attributes).

As an illustrative example, the Fig. 6 below displays an example of visualization for the "Ecosystem view" (Part of the set of contextual views). Consistently with the meta-model (Fig. 2, Ecosystem view), there are four modelling objects available for this specific view (center of the figure): two types of actors (Economic and Non-economic Actors), then two types of relationships among these actors ('Interacts with' to represent any kind of actor interaction, and 'Financial transaction' to represent economic transactions among actors). The Fig. 6 also illustrates an example of model instantiation for a specific case of ecosystem, with the stakeholders and all the relationships.

Following this development approach, the full meta-model presented (Fig. 5) led to implement a Modelling Library covering the specifications of the ten modelling views. This Library implements all the modelling objects separately, with respect to the conceptual specifications of the meta-model. The Library is an intermediary output of the technical development process.

ADOxx meta-modelling platform supports the easy implementation of this Modelling-Library into a dedicated modelling toolkit. The toolkit implementation can be understood as a customization of a pre-defined existing modelling environment: this customization process offers a great help to accelerate the overall implementation process. The final modelling toolkit (sPS^{2}Modeller) provides all necessary functionalities to create models for any new smart PSS design project and to manage the life cycle of the models during the entire design project. The utilization of the tool is illustrated in Section 5.

5. Output-3: Experimental application case

As emphasized in the previous sections, this paper addresses the current lack of modelling language required to support efficiently the early-design prototyping of smart PSS value offers, by proposing a meta-model and its technical implementation. The resulting modelling tool sPS^{2}Modeller and usage method are generic and quite independent of any specific context: they have been built to answer the generic requirements for smart PSS early design, and the industrial requirements captured at elm.leblanc concerning the tool did not reduce the

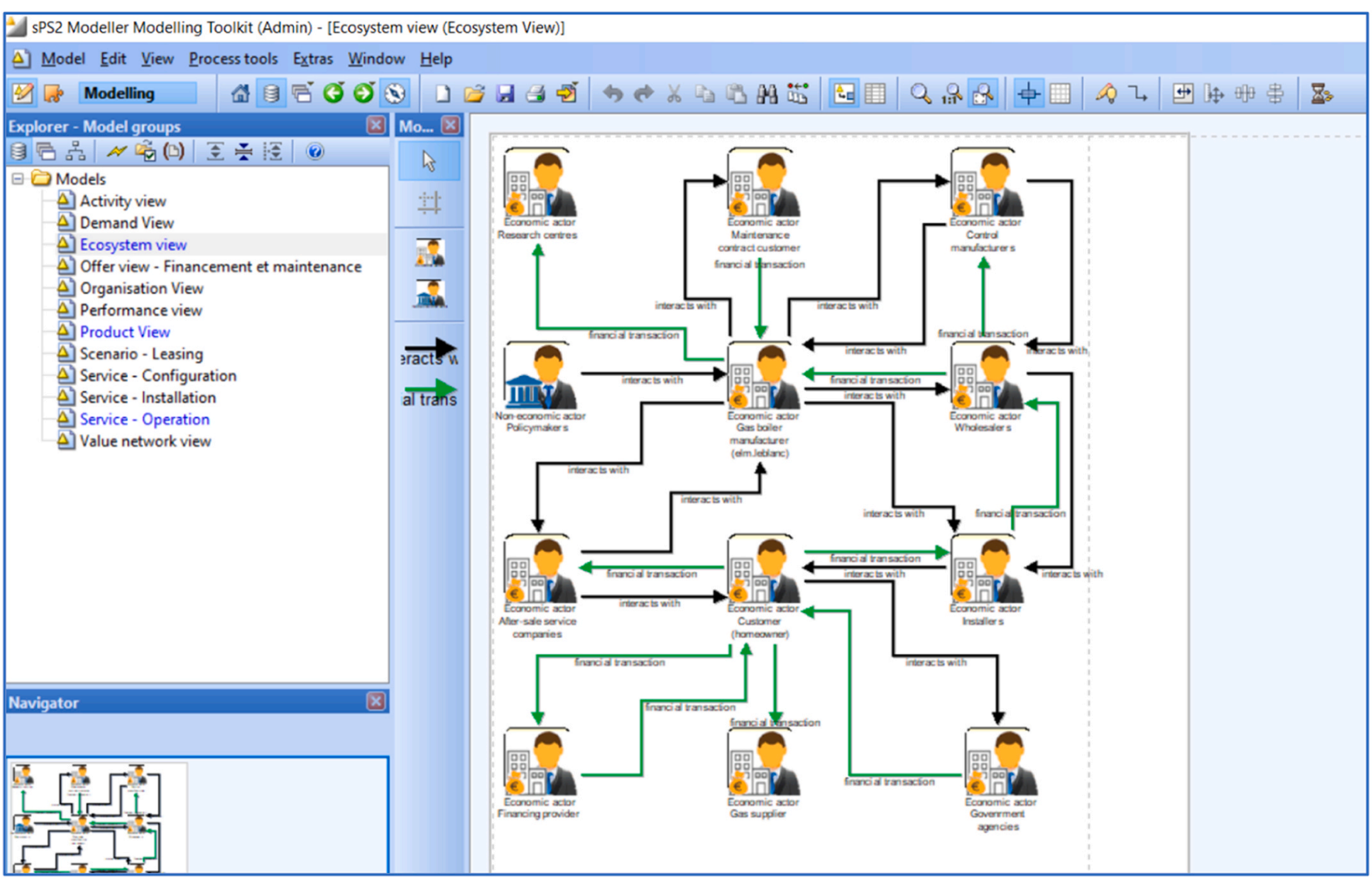

Fig. 6. Example of Ecosystem Modelling View.

genericity but ensured the integration of very operational and pragmatic needs from field designers. The level of genericity is further discussed in Section 7.

The industrial utilization of this new modelling language should be integrated with a consistent design framework, which could structure the different steps (and iterative loops) of value offer development and, thus, the way to utilize sPS^{2}Modeller. This framework, called SPS^2 Risk Framework, was built by the authors to support the experimental validation and published in (Murillo-Coba et al., 2023a; Murillo-Coba, 2022). However, the presentation of SPS^2 Risk Framework is not the objective of the current paper, and we suggest to the lecturer to refer to complementary publications (Murillo Coba et al., 2020) (Murillo-Coba, 2022).

As put forth in Section 3.4, the application case provides an applicability verification but not a full validation process. Thus, the following sections focus on presenting the case study and the outputs of the modelling language utilization (sPS^{2}Modeller). The objectives are (i) to illustrate the operational results of the technical developments linked to a real utilization, then (ii) to discuss the feasibility and practicability of the approach presented in this paper for early-design value offer prototyping.

5.1. Industrial application case for feasibility experimentation

This section first introduces the industrial context of the smart PSS design experimentation before highlighting the experimental procedure itself. As introduced in Section 2, this research was developed in collaboration with the industrial company elm.leblanc, Bosch Group France. The industrial case study is thus developed in the field of heating production systems: elm.leblanc is an international leader in design and manufacturing such systems. 'Heat-as-a-Service' (HaaS) has emerged as a prospective business embracing the challenges posed by the energy transition, with 'heating-appliance-as-a-service' selected as a case study (concrete example, referred in Fig. 7). This variant implies that the customer pays a 'service provider' a recurring fee for the use of the heating appliance instead of the traditional upfront payment for the heating system and its installation. Connected heating appliances are likely to be included in this offering, with potential to offer a variety of digital services to the user.

A connected heating appliance can be controlled remotely, unlike a conventional one (i.e., the user can control their heating and hot water from their phone or other devices). This functionality facilitates the delivery of digital services, such as the remote monitoring of the appliance aimed to predict failures. When the sensor installed in the appliance identifies the probability of occurrence of a breakdown, it alerts the service engineer or installer about the incident and the spare part that needs to be replaced. The customer is also informed about the breakdown and the time that it will take for the service engineer to travel to their home and repair the heating appliance. Consequently, Smart PSS offerings in the residential heating business include a bundle of connected appliances with classical and digital services to satisfy customers' needs. As heating appliance manufacturers do not usually have all the expertise and resources to deliver these packaged solutions, they need to establish partnerships with external actors. Among these

Fig. 7. Snapshot of the advertising of a service-oriented offering commercialized by Bosch.

actors, we can mention IT-related companies, installers, after-sale service firms, finance providers, and reverse logistic partners. In this value network perspective, the notion of win-win outcomes becomes decisive in the design process.

The feasibility experimentation constitutes the last step 3.1 of the methodology (Fig. 1). This research methodology is based on a high level of interaction between industrial actors and the researchers: after all the exchanges required to define and implement the modelling language, the main researcher (PhD candidate) was integrated in a regular process of interaction with a Design team working on an HaaS innovative project. This design process for a new smart PSS thus supported the validation of the modelling language proposed in this paper. The design process was structured according to the Design SPS^2 Risk Framework mentioned earlier (Murillo-Coba, 2022), with the PhD researcher directly involved in the design team in order to capture all elements of information required for the use of the modelling views. Of course, during this experimental period, the presence of the PhD candidate within the design team transformed the collective competence of the industrial team and thus introduces some biases with regards to a pure industrial situation. However, this collaborative and constructivist approach presents the interest to make possible an immediate and full experimentation of the utilization of the modelling language as cognitive support to mediate the interaction between the designer, to capture a consistent applicability feedback. Only in a second phase, experimentations independent of the researcher are planned to be launched.

The utilization of the modelling language was tested on the ten views of the Modelling Language, as reported below.

5.2. Experimentation of the contextual views

The contextual views are utilized at different phases of the smart PSS design process.

At a very early design stage, the Ecosystem view was used to capture of strategic pieces of information on key Business model stakeholders. A strategic contextualization was carried out to determine the focal firm's position against new initiatives that are likely to reshape the heating business. The residential heating field is characterized by fierce competition and the influence of important factors such as energy suppliers who offer heating installation services and maintenance contracts. The government's efforts to decarbonize heating undoubtedly impact the focal firm's strategy, as bans on new oil- and gas-powered heating appliances from new homes have come into effect. However, the customer affordability of high-energy-efficient heating systems and their associated operational costs may hinder these efforts. The internal strategic analysis highlighted the brand's reputation in the market, the products' reliability, the technicians' know-how, and the existing partnership with certified installers. Considering the French market's size and the heating replacement rates, the customer segment corresponding to heating system replacement in individual private homes was targeted for the design of service-oriented offerings. The map of the stakeholders involved in this segment was modeled in the 'ecosystem view' of sPS^{2}Modeller (Fig. 6). Based on this representation two stakeholders were identified as crucial for the Business Model development, besides the main company elm.leblanc: (1) the private homeowners interested in replacing their heating system and (2) the installers. The latter are key actors in the product-based value chain as manufacturers rely on installers to market their products to private homeowners. Then, a service-oriented business model should include them, as elm.leblanc does not have direct distribution channels to customers.

The second contextual view, the Organizational view, is used much later in the design process (Murillo-Coba, 2022) to describe the collective capabilities of the potential partners of the smart PSS delivery networks. Each organizational actor is identified (if required, decomposed into sub-unit), and characterized by the type of macro-activities or simply activity it has the capability to take in charge in the context of smart PSS delivery network. This is somehow a declarative map of the available organizational capabilities. The key risks assumed by organizational actors, which could have an effective impact on the delivery of smart PSS solutions, are also identified in this map (see Fig. 8, with three main organizational risks identified in the case study). This contributes to the overall Risk identification along the whole value creation process. Note also, that the value and delivery network will be modelled in other modelling views (see Section 5.4), with reference to the organizational actors defined in this organizational map.

5.3. Experimentation of the structural views

A brainstorming session was conducted considering the insights collected from key stakeholders as input. The transdisciplinary design team of the focal company came up with a service-oriented value proposition. The products and services included in this value proposition were modelled in the sPS^{2}Modeller. This value proposition can be summarized as follows: (i) the availability of the heating appliance, (ii) the services included in the traditional after-sales contract (e.g., annual routine maintenance, repairs), (iii) the remote monitoring of the heating appliance, and (iv) energy consumption monitoring. The heating appliance can be either a gas boiler or a heat pump. The constituting elements of the value proposition were modelled in the ‘product’ and ‘service’ modelling views. An example of service view if provided with Fig. 9. In this figure, we focus on a specific stage of the lifecycle which is the removal and replacement of a heating appliance. This stage involves two actors: the private homeowner and the installer. The former is being delivered different services such as removal of the old appliance and installation and commissioning of the new system, while the latter has access to technical support and payment delivery.

Following the logic of the design framework, the transdisciplinary team configures the value offering. In other words, the team establishes how the value proposition will be sold. Considering the outcomes of the brainstorming session, the team decided to explore the possibility to commercialize three subscriptions. These subscriptions belong to either a product- or a use-oriented economic model. The subscription following a product-oriented logic is called ‘financing and maintenance’. The remaining subscriptions belonging to the use-oriented economic model are called ‘leasing’ and ‘rental’ (Table 4). The modelling procedure in the ’offer’ view enabled the team to address questions such as “what services and products can be included in each subscription’.

As a result, two services packages called ‘PSS’ and ‘Smart PSS’ were included in each subscription. This modelling procedure supported the discussion of aspects regarding the contractual relations between the subscription provider and the client, and led to build the offer view (Fig. 10) which includes the description of the subscription contract as well as of the package of services included in the PSS offer. Later in the design process, the ‘activity’ modelling view is employed. This modelling view is aimed to enable the team to list the activities required to deliver the Smart PSS offering. More specifically, the activities involved in the provision of the products and services embedded in the value proposition (e.g., the appliance manufacturing, installation, spare part supply).

5.4. Experimentation with the dynamic views

The customer segment targeted by the brainstormed service-oriented value proposition, the private homeowner market, was characterized in the ‘demand’ view. The demand related to the retrofit of heating appliances in this customer segment was quantified based on the insights provided by a consulting firm, then saved in the modelling objects of this view. At a later stage in the design process, the indicators proposed to evaluate the performance of the value networks delivering the Smart PSS offering are modelled in the ‘performance’ view. Economic performance indicators such as sales revenue and net profit for each key value network actor were modelled.

The two first dynamic views (‘demand’ and ‘performance’ views) gather basic pieces of design information to prepare a further step of design, consisting in defining operational solutions (multi-actor networks) to deliver smart PSS offers. Here, the ‘scenario’ and ‘value network views’ are used as design support. Each value offering

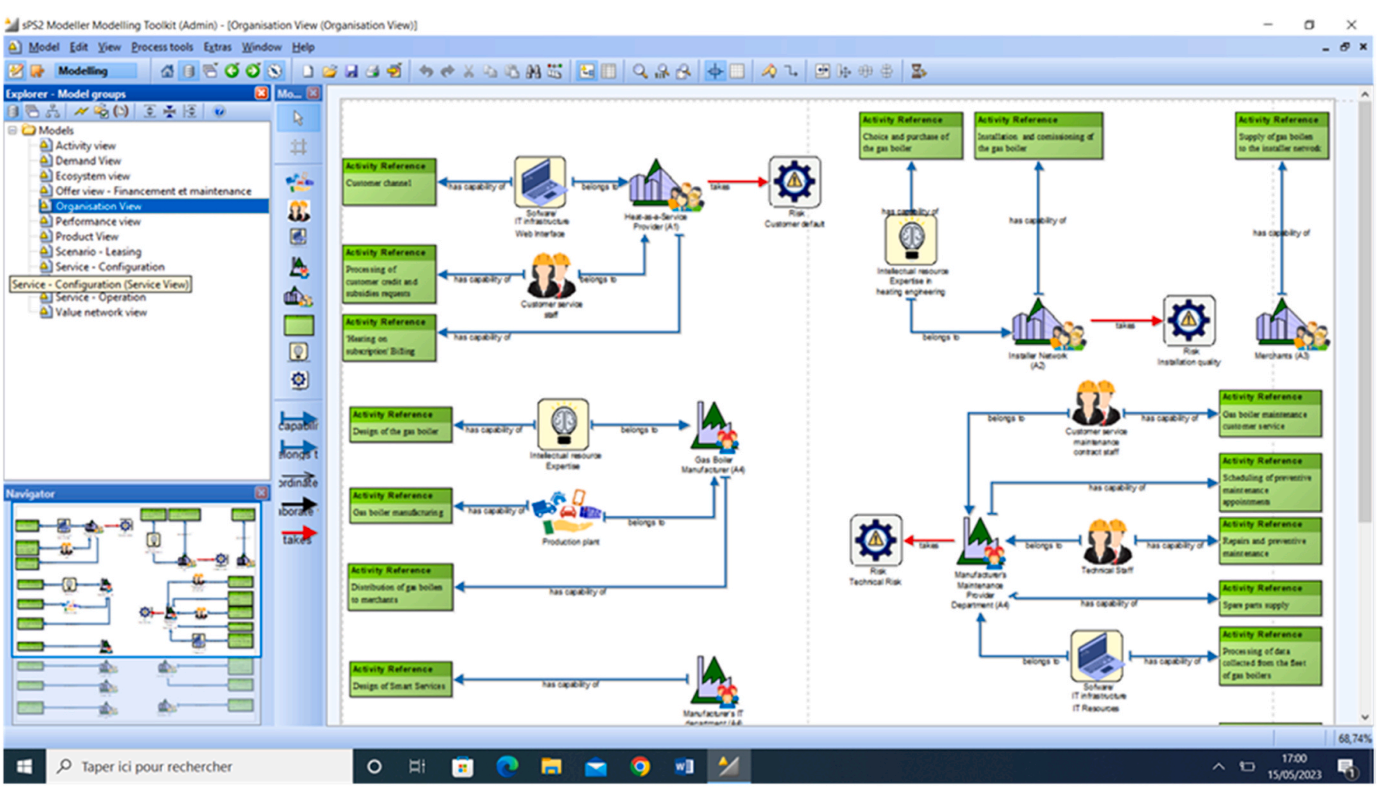

Fig. 8. Organizational view for the case study.

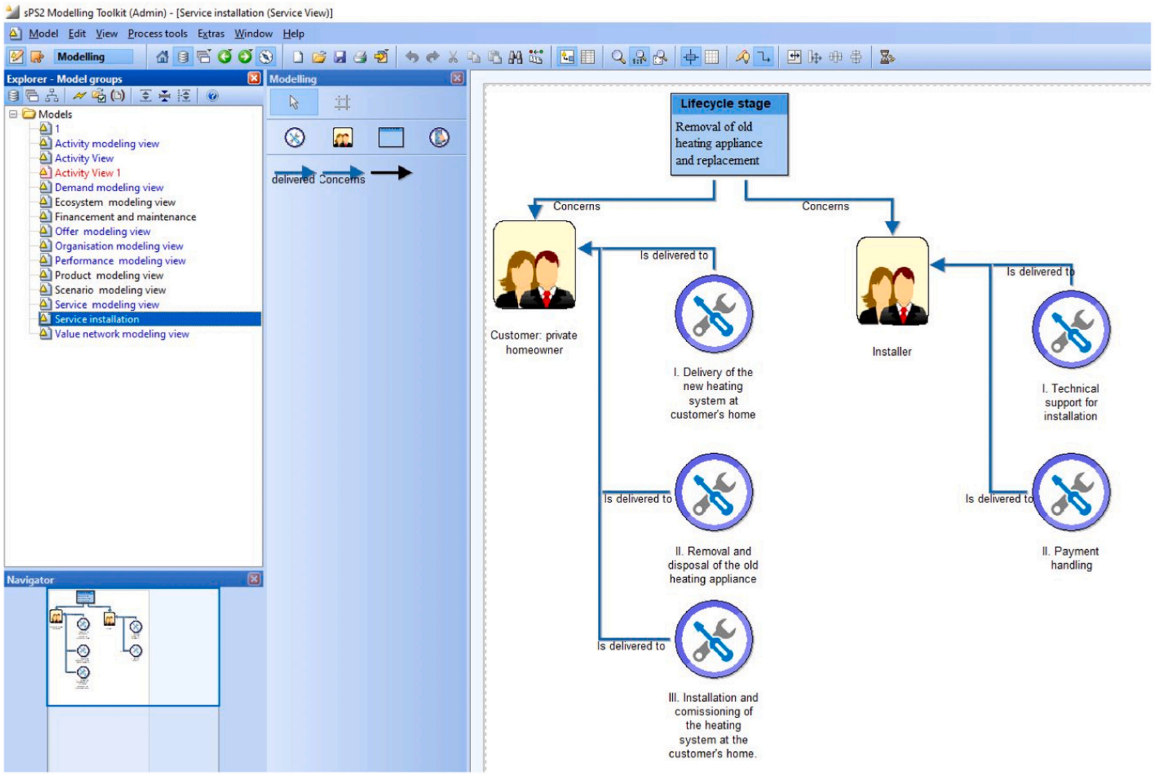

Fig. 9. Snapshot of the service view for the case study.

Table 4
Main characteristics of the economic models considered in the case study.

Type of Economic model	Financing and maintenance Product-oriented	Leasing Use-oriented	Rental Use-oriented
Average subscription period in the existing offerings	Five years	From eight to twelve years	Minimum two years; after this period, the subscription duration is indefinite. This means that the client can cancel the subscription anytime.
What happens when the customer cancels the subscription?	The client must reimburse the remaining amount of the credit, and the maintenance contract is suspended.	The client can either buy the appliance for its residual value or have it uninstalled. The only valid options to end the subscription are the death of the client or the sale of the client's home.	The appliance is uninstalled with no option to buy it.

combining an economic model (i.e., financing and maintenance, leasing, and rental), and a service package (i.e., PSS, Smart PSS) was modelled in the 'scenario view'. In this modelling view (Fig. 11), the team defined the internal and external actors required to deliver the Smart PSS offering (i.e., the installer network, a third-party playing the 'service provider' role, etc.). Then, these actors were assigned roles related to the macro-activities needed to ensure Smart PSS provision. Additionally, the economic performance indicators were associated with each key actor. Once, the Smart PSS delivery scenarios were defined, the financial transactions and the deliverables exchanged among the actors were graphically represented using the 'value network' modelling view. This activity was carried out for each scenario model drawn on the 'scenario' modelling view. During the design, these Smart PSS value networks are used to support the identification of the key parameters of economic flows and transactions for each actor: each actor is characterized in terms of cost objects, and revenue model. Even if it is out of the scope of this paper, it is important to understand that all these economic parameters will be later re-used in further steps of SPS^2 Risk Framework: this information is necessary for the profitability assessment of the value networks, through a smart PSS simulation presented in (Boucher et al., 2019).

6. Discussions

6.1. Feedback on usability of the prototyping toolkit and contributions to the practice

The real context setting of the case study reported in the previous section offered the opportunity to test and verify the applicability of the meta-model and its derived modelling toolkit. This experimentation showed an easy appropriation of this conceptual prototyping approach by the industrial actors, with very little resistance about the modelling tasks required, an easy learning/adoption of the modelling environment and a strong interest for the collective interactions mediated by the visual representation of these value-oriented prototypes. We highlight in the following sections two contributions of the digital prototypes to field practices for smart PSS design, i.e (i) 'early-design information traceability' and (ii) 'multi-actor coordination' together with a (iii) skill-oriented limitation of the approach.

First, the use of sPS^{2}Modeller ensures an important functionality of design information traceability. While respecting the large diversity of design pieces of information, induced by the value orientation of the design process, the modelling language implemented into 10 modelling views offers an ergonomic structuration of the set of design pieces of information. The progressive use of the 10 modelling views, following

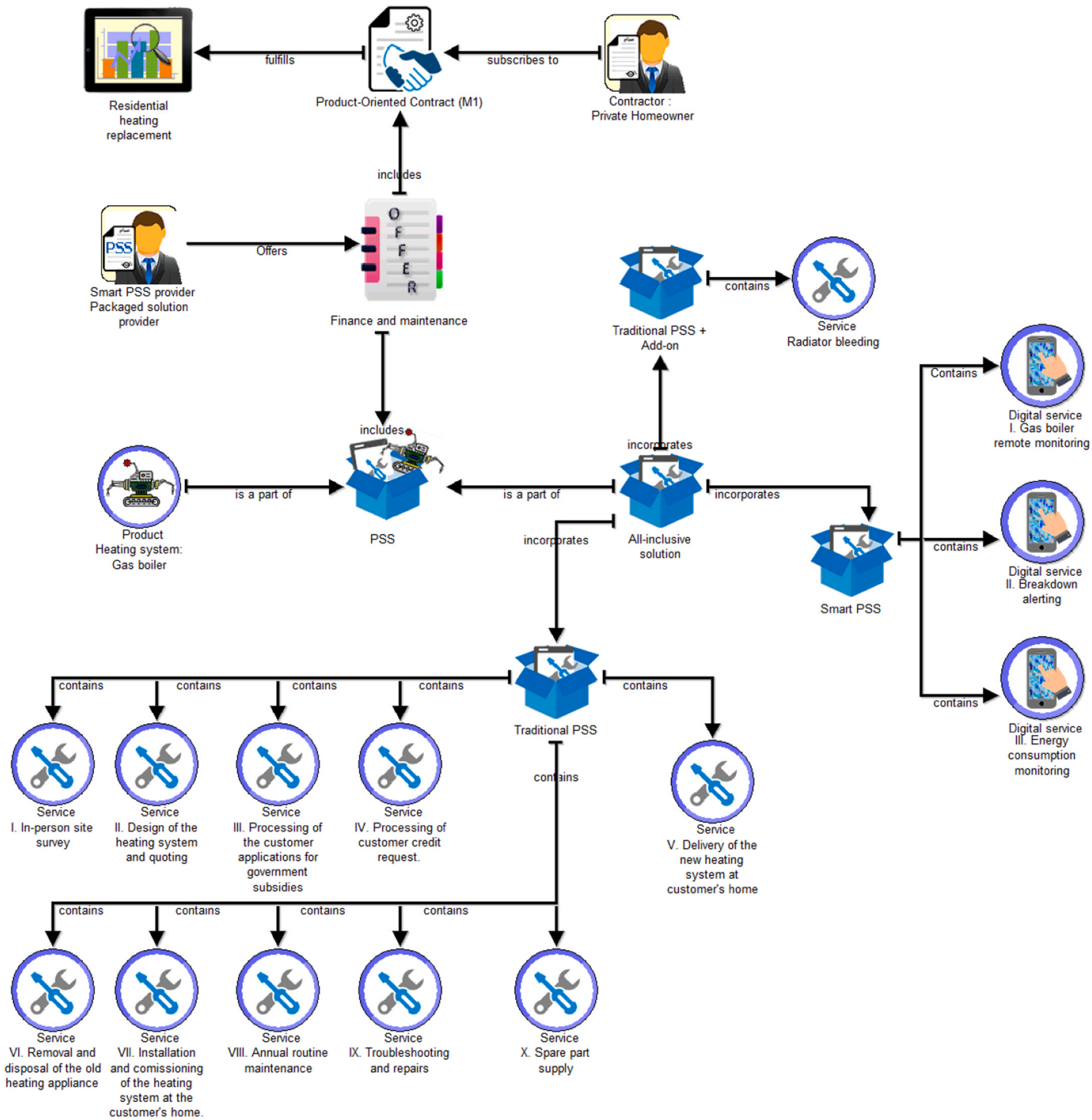

Fig. 10. Snapshot of the 'offer' modelling view on sPS^{2}Modeller for the 'Financing and maintenance' subscription.

the various steps of sPS^2 Risk Framework, favors an incremental capture of the whole set of design information. The information remains easily accessible for any design actor, through an ergonomic visualization approach. However, even larger perspectives of traceability could be studied in the future: by addressing value offer prototyping, sPS^{2}Modeller is linked to all aspects of the smart PSS design and, consequently, could be interfaced with other design databases used during the process. The tool is also included in a process of iterative design: the versioning management for all conceptual prototypes should be carefully considered. Such technical and integration issues are out of the scope of the current research but could be studied later.

Second, the digital prototypes of Smart PSS value offerings ensure the additional functionality of helping multi-actor coordination, by boosting the collective intelligence process. Literature reports that Smart PSS providers need to create transdisciplinary teams to develop new value offers (Huikkola et al., 2022). The digital prototypes help gathering the technical, commercial, financial, and IT-related knowledge and data necessary to iteratively co-design these service-based and digital-enabled offerings. These cross-functional data and knowledge are shaped into conceptual models exploiting the visual thinking technique. The graphical representations of the conceptual models constitute a shared language, at the interface between the various technical domains involved in the design team, facilitating the confrontations of needs, constraints and solutions among all actors. The application of this

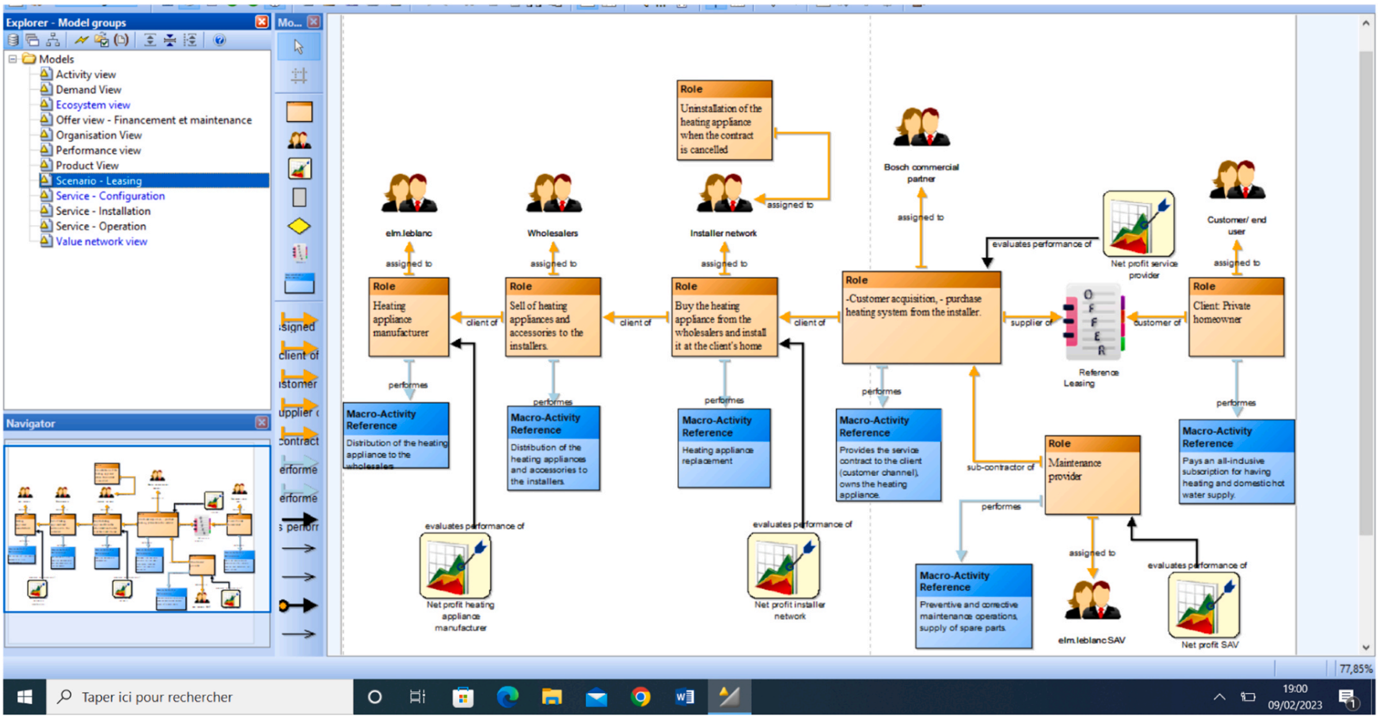

Fig. 11. Example of scenario view.

technique facilitates the visualization of the Smart PSS value architecture's subcomponents and, thus, reduces the cognitive effort necessary to depict the interactions among the value proposition, the value network, and the value capture mechanisms. Additionally, thanks to the visualization, testing these digital prototypes with internal and external stakeholders of the Smart PSS provider can bring important insights into the Smart PSS offering's customer desirability, technical feasibility, and economic viability (Lewrick et al., 2018). Of course, this ability to facilitate collective coordination and decision-making also depends a lot of the integration of the tool itself within a design process catalyzing interactions and collective decision-making. In this perspective, we refer to the associated SPS^2 Risk Framework (Murillo-Coba at al., 2023a).

However, practical limitations remain to be addressed. A difficulty of implementing sPS^{2}Modeller in an industrial setting concerns the acquisition of the necessary skills to utilize the modelling platform's interface and the procedure to draw the conceptual models. In this regard, the Smart PSS development project manager would have to devote additional time to assimilate the conceptual prototyping approach. During the Smart PSS design process, this project manager should transfer such modelling skills to the rest of the design team to ensure easy iterative prototyping.

6.2. Managerial implications

The managerial impacts of this early-design prototyping approach concern smart PSS Design Project managers, with two main added-values: (i) a new support for the industrial deployment of Design Thinking approaches and (ii) a contribution to help managing the complexity of value driven design.

First, the smart PSS modelling language and value-proposition prototyping toolkit presented in this paper, provide an interesting added-value to facilitate and boost the deployment of the Design Think approach on complex projects. The full set of modelling views proposed to be built along the early-design phases of the project constitute an interesting visualization of some of the key components of the business model which need to be defined in smart PSS design projects: the local Ecosystem linked to the smart PSS offer, the key technical components of the PSS Offer, the catalog of services which can be offered along the lifecycle, the configuration one or several value propositions embedding technical and service components articulated via a dedicated contractualization proposal, the Value Network in charge to implement the offer on the market (together with its key economic parameters). By offering graphical visualization of these important pieces of knowledge defined at early design time, this prototyping toolkit facilitates and reinforces the deployment of the Design Thinking process and notably the necessary confrontation among the various designer's points of view for the configuration of the value proposition and value network. This intends to answer the need to make more tangible the multiple components of a value proposition (Exner et al., 2014; Valencia Cardona et al., 2014; Trevisan and Brissaud, 2017; Hagen et al., 2018; Ilg et al., 2018).

A second managerial added-value of this prototyping approach is to bring a way to manage the complexity inherent to value-driven design. This complexity is notably induced by the numerous dimensions of the value-design, the high level of potential diversity in the way to configure the market offer and the various design and engineering cultures involved in the multi-disciplinary design team. The main support of the prototyping approach to manage complexity is linked to information structuration and visualization. The structuring modelling views generates a progressive procedure for the usage of sPS^{2}Modeller, which guides the whole design team in progressive objective of design: somehow this is encapsulating some organizational knowledge. Additionally, the graphical visualization of all conceptual models (including ecosystem, service offer, value offer, delivery network, value network, etc.) supports the designers with an easy concretization of the subcomponents of the design process, reducing the cognitive complexity. As such, the expected impacts are to increase the level of coordination and mutual adjustment among designers and thus to contribute reducing the duration of design projects. We remind to the reader that the full design method using SPS^{2}Modeller has been formalized with the so-called SPS^2 Risk Framework mentioned earlier (Murillo-Coba, 2022), which remains out of the scope of the current paper.

7. Conclusions and perspectives

In the context of value-driven design of smart PSS, this paper presents the development and experimentation of an operational solution to support and help value-offer design, via the use of conceptual prototypes, which offer a capacity of visualization and virtualization of key components of the value system under design. The paper presents the three key outputs generated by this research work: (i) the conceptual meta-model which defines the smart PSS – oriented modelling language, (ii) the associated modelling toolkit sPS^2Modeller and (iii) an industrial application. The industrial experimentation, leaded by the company elm.leblanc (Bosch France) in the field of connected heating appliances, emphasizes the added-value of the approach in terms of (i) traceability of design information and knowledge for the whole design project, (ii) support for cognitive interactions and decision-making in a multi-actor context and (iii) facilitator for the deployment of Design Thinking approaches and (iv) help to manage the complexity inherent to value-driven design.

The full potential of the tool depends of complementary aspects of this research: the deployment of its utilization encapsulated in well-structured smart PSS Design Framework (sPS^2 Risk Framework), together with the articulation between this qualitative prototyping approach and complementary quantitative prototypes supporting industrial decision-makers. Thus a first perspective, complementary to the design of a smart PSS value proposition and its network of actors through sPS^2 Modeller, a quantitative assessment of design risks could be developed through a quantitative simulation tool. Concerning economic risks, changing or diversifying a company's offering can have a severe effect on its viability, if not properly considered from the beginning and it can even lead to a setback for the company and a loss of competitiveness. In addition, when a company switch from selling products to selling the usage of these products (servitization), it may lose one-time payments that could, in the end, affect its working capital. Partnerships with new stakeholders - service provider, maintenance provider, financial partner, etc. - become necessary, which changes the types of financial flows between actors. Hence, based on these economic relations among actors, expressed in sPS^2Modeller as financial transactions (see Fig. 6), it is possible to try and validate the economic viability of the smart PSS offering by running mid or long-term simulations considering various scenarios. A first simulation platform named sPS^2Simulator is currently under development in this perspective: the simulator runs what-if scenarios in order to estimate the robustness of the alternative smart PSS networks together with their associated economic models. The ambition of this work is also to go beyond the sole economical point of view and to integrate other indicators such as carbon footprint, which could give insights on one aspect of sustainability for the network.

Besides, an enlarged validation protocol remains necessary. If the modelling tool sPS^2Modeller has been designed to be as generic as possible, relying on the capture of industrial requirements and on the expertise of people whose background is not only related to the focused production system, its applicability has only been verified on one single case study until now. Hence, the proposed sPS^2Modeller could benefit from further applicability assessments in other industrial sectors, thus extending the application spectrum. To move from the "verification" stage to a more global "validation", collaborating with other R&D teams seems appropriate to verify applicability to their own industrial context. Both qualitative and quantitative assessment and validation protocol could be defined. Depending on the outcomes of these applications, improving the tool and generalizing some features and prototyping views to cover specific situations could be required. Such updates would be easily achievable because of the long-term collaboration between sPSS academics and the ADOxx metamodeling platform used to implement sPS^2Modeller.

Author statement

In the name of all authors of this research, I hereby confirm that this research work is fully original and does not use at all any generative artificial intelligence.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Camilo Murillo-Coba reports financial support was provided by Association Nationale de Recherche Technologique (ANRT-France). Xavier Boucher reports a relationship with French National Research Agency that includes: funding grants.

Data availability

The data that has been used is confidential.

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References

Abramovici, M., Neubach, M., Schulze, M., & Spura, C. (2009). Metadata reference model for IPS2 lifecycle management. In *Proceedings of the 19th CIRP Design Conference–Competitive Design*. Cranfield University Press.

Andriankaja, H., Boucher, X., Medini, K., 2018. A method to design integrated product-service systems based on the extended functional analysis approach. CIRP J. Manuf. Sci. Technol. 21, 120–139.

Baines, T.S., Lightfoot, H.W., Benedettini, O., Kay, J.M., 2009. The servitization of manufacturing: A review of literature and reflection on future challenges. J. Manuf. Technol. Manag.

Blessing, Chakrabarti, 2009. DRM, a Design Research Methodology. Springer,, Dordrecht, pp. 13–42.

Boucher X., Murillo-Coba C., Medini K., (2019). Framework to model PSS collaborative value networks and assess uncertainty of their economic models, PRO-VE 2019, 20th IFIP Working Conference on Virtual Enterprises, 23–25 September 2019 – Turin, Italy.

Boucher, X., Pezzotta, G., Pirola, F., Wiesner, S., 2022. Digital technologies to support lifecycle management of smart product-service solutions. Comput. Ind. 141, 103691. October 2022.

Buchmann, R.A., 2016. Modeling product-service systems for the internet of things: The comvantage method. Domain-specific conceptual modeling. Springer,, Cham, pp. 417–437.

Cenamor, J., Rönnberg Sjödin, D., Parida, V., 2017. Adopting a platform approach in servitization: leveraging the value of digitalization. Int. J. Prod. Econ. 2017 (192), 54–65. https://doi.org/10.1016/j.ijpe.2016.12.033.

Chang, D., Gu, Z., Li, F., Jiang, R., 2019. A user-centric smart product-service system development approach: A case study on medication management for the elderly. Adv. Eng. Inform. 42, 100979.

Cimini, C., Adrodegari, F., Paschou, T., Rondini, A., Pezzotta, G., 2021. Digital servitization and competence development: A case-study research. CIRP J. Manuf. Sci. Technol. 32, 447–460.

Da Costa Fernandes, S., Pigosso, D.C., McAloone, T.C., Rozenfeld, H., 2020. Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. J. Clean. Prod. 257, 120507.

Da Silva, A.R., 2015. Model-driven engineering: A survey supported by the unified conceptual model. Comput. Lang., Syst. Struct. 43, 139–155.

Dewit, I., Jacoby, A., Matthyssens, P., 2021. Design Preconditions for Product—Service Integration. Designs 5 (2), 29.

Ellström, P.E. (2007). Knowledge creation through interactive research: A learning perspective. In *HHS-07 Conference, Jönköping University, 2007 May* (pp. 8–11).

Exner, K., Lindow, K., Buchholz, C., Stark, R., 2014. Validation of product-service systems–a prototyping approach. Procedia CIRP 16, 68–73.

Exner, K., Lindow, K., Stark, R., Ängeslevä, J., Bähr, B., & Nagy, E. (2015). A transdisciplinary perspective on prototyping. In *2015 IEEE International Conference on Engineering, Technology and Innovation/International Technology Management Conference (ICE/ITMC)* (pp. 1–8). IEEE.

Exner, K., Damerau, T., Stark, R., 2016. Innovation in Product-Service System Engineering based on early customer integration and prototyping. Procedia Cirp 47, 30–35.

Fargnoli, M., Haber, N., Sakao, T., 2019. PSS modularisation: a customer-driven integrated approach. Int. J. Prod. Res. 57 (13), 4061–4077. https://doi.org/10.1080/00207543.2018.1481302.

Fialho, B.C., Codinhoto, R., Fabricio, M.M., Estrella, J.C., Ribeiro, C.M.N., Bueno, J.M.D. S., Torrezan, J.P.D., 2022. Development of a BIM and IoT-based smart lighting maintenance system prototype for universities' FM sector. Buildings 12 (2), 99.

Gaiardelli, P., Boucher, X., West, S., Pezzotta, G., 2023. Product-Service Systems: definitions and design approaches. Section 10, chapter 58. In: Bidanda, B. (Ed.), Maynard's Industrial and Systems Engineering Handbook, 6th edition.,. McGraw Hill Professional, New York, pp. 1127–1154. Section 10, chapter 58.

Haber, N., Fargnoli, M., Sakao, T., 2020. Integrating QFD for product-service systems with the kano model and fuzzy AHP. Total Qual. Manag. Bus. Excell. 31 (9–10), 929–954. https://doi.org/10.1080/14783363.2018.1470897.

Hagen, S., Kammler, F., Thomas, O., 2018. Adapting product-service system methods for the digital era: requirements for smart PSS engineering. Cust. 4. 0 87–99.

Hara, T., Arai, T., Shimomura, Y., 2009. A CAD system for service innovation: integrated representation of function, service activity, and product behaviour. J. Eng. Des. 20 (4), 367–388. https://doi.org/10.1080/09544820903151715.

Huikkola, T., Kohtamäki, M., Ylimäki, J., 2022. Becoming a smart solution provider: Reconfiguring a product manufacturer's strategic capabilities and processes to facilitate business model innovation. Technovation, 102498.

Idrissi, N.A., Boucher, X., Medini, K., 2017. Generic conceptual model to support PSS design processes. Procedia CIRP 64, 235–240.

Ilg, J., Wuttke, C.C., Siefert, A., 2018. Systematic prototyping of product-service systems. Procedia CIRP 73, 50–55.

Kaiser, C., Stocker, A., Viscusi, G., Fellmann, M., Richter, A., 2021. Conceptualising value creation in data-driven services: The case of vehicle data. Int. J. Inf. Manag. 59, 102335.

Karagiannis, D., Buchmann, R.A., Burzynski, P., Reimer, U., Walch, M., 2016. Fundamental conceptual modeling languages in OMiLAB. In: Karagiannis, D., Heinrich, M., Mylopoulos, C.J. (Eds.), Domain-Specific Conceptual Modeling, Concepts, Methods and Tools. Springer International Publishing, Switzerland.

Karagiannis, D., Buchmann, R.A., Utz, W., 2022. The OMiLAB Digital Innovation environment: Agile conceptual models to bridge business value with Digital and Physical Twins for Product-Service Systems development. Comput. Ind. 138, 103631.

Lamperti, S., Cavallo, A., Sassanelli, C., 2023. Digital servitization and business model innovation in SMEs: a model to escape from market disruption. IEEE Trans. Eng. Manag. 2023, 1–15. https://doi.org/10.1109/TEM.2022.3233132.

Lee, C.H., Chen, C.H., Trappey, A.J., 2019. A structural service innovation approach for designing smart product service systems: Case study of smart beauty service. Adv. Eng. Inform. 40, 154–167.

Lewrick, M., Link, P., Leifer, L., 2018. The design thinking playbook: Mindful digital transformation of teams, products, services, businesses and ecosystems. John Wiley & Sons,.

Liu, Z., Ming, X., 2019. A methodological framework with rough-entropy-ELECTRE TRI to classify failure modes for co-implementation of smart PSS. Adv. Eng. Inform. 42, 100968.

Liu, Z., Ming, X., Song, W., Qiu, S., Qu, Y., 2018. A perspective on value co-creation-oriented framework for smart product-service system. Procedia CIRP 73, 155–160.

Lüttenberg, H., 2020. PS 3–A domain-specific modelling language for platform-based smart service systems. In International Conference on Design Science Research in Information Systems and Technology. Springer,, Cham, pp. 438–450.

Maleki, E., Belkadi, F., Bernard, A., 2018a. A meta-model for product-service system based on systems engineering approach. Procedia CIRP 73, 39–44.

Maleki, E., Belkadi, F., Bernard, A., 2018b. Industrial Product-Service System modelling base on Systems Engineering: Application of sensor integration to support smart services. IFAC-Pap. 51 (11), 1586–1591.

Medini, K., Boucher, X., 2019. Specifying a modelling language for PSS Engineering–A development method and an operational tool. Comput. Ind. 108, 89–103.

Müller, P., Kebir, N., Stark, R., Blessing, L., 2009. PSS layer method–application to microenergy systems. Introduction to product/service-system design. Springer,, London, pp. 3–30.

Murillo Coba C., Boucher X., Vuillaume F., Gay A., Gonzalez-Feliu J., (2020). Value Proposition in Smart PSS Engineering: Case Study in the Residential Heating Appliance Industry, PRO-VE 2020, 21st IFIP Working Conference on Virtual Enterprises, 23–25 November 2020 – Valencia, Spain.

Murillo-Coba, C. (2022). A risk-oriented framework for Smart PSS design, considering value network and economic model configuration, PhD thesis, Lyon-University, Mines-Saint Etienne, Oct. 2022.

Murillo-Coba C., Boucher X., Lamy D., Vuillaume F., Gay A., (2023a). Design and engineering of value-driven Smart PSS for manufacturing companies: design risk anticipation with sPS2Risk Framework, CIRP Journal of Manufacturing Science and Technology, submitted for publication 2022, corrected January 2023, under final step of correction.

Murillo-Coba, C., Lamy, D., Boucher, X., 2023b. PSS Economic model simulation and risk assessment: lessons from an industrial case study. In: Pezzotta, G., Sala, R., Boucher, X., Bertoni, M., Pirola, F. (Eds.), Data Driven Decision Making for Product Service System. Springer International Publishing, Switzerland.

Mylopoulos, J., 1992. Conceptual modelling and Telos. Concept. Model., Databases, CASE: Integr. view Inf. Syst. Dev. 49–68.

Orellano, M., Lambey-Checchin, C., Medini, K., Neubert, G., 2021. A Methodological Framework to Support the Sustainable Innovation Development Process: A Collaborative Approach. Sustainability 13 (16), 9054.

Osterwalder, A., Pigneur, Y., 2010. Business model generation: a handbook for visionaries, game changers, and challengers, 1. John Wiley & Sons,.

Parida, V., Sjödin, D., & Reim, W. (2019). Reviewing literature on digitalization, business model innovation, and sustainable industry: Past achievements and future promises.

Paschou, T., Rapaccini, M., Adrodegari, F., Saccani, N., 2020. Digital servitization in manufacturing: A systematic literature review and research agenda. Feb. 2020 Ind. Mark. Manag.. https://doi.org/10.1016/j.indmarman.2020.02.012.

Peffers, K.; Tuunanen, T.; Gengler, C.E.; Rossi, M.; Hui, W.; Virtanen, V.; Bragge, J. The Design Science Research Process: A Model for Producing and Presenting Information Systems Research. In Proceedings of the 1st International Conference, DESRIST 2006 Proceedings. Claremont Graduate University; 2006; Vol. 2, pp. 83–106.

Pezzotta, G., Pirola, F., Rondini, A., Pinto, R., Ouertani, M.-Z., 2016. Towards a methodology to engineer industrial product-service system—evidence from power and automation industry. CIRP J. Manuf. Sci. Technol. 15, 19–32. https://doi.org/10.1016/j.cirpj.2016.04.006.

Pezzotta, G., Sassanelli, C., Pirola, F., Sala, R., Rossi, M., Fotia, S., Koutoupes, A., et al., 2018. The product service system lean design methodology (PSSLDM): integrating product and service components along the whole PSS lifecycle. J. Manuf. Manag. 29 (8), 1270–1295. https://doi.org/10.1108/JMTM-06-2017-0132.

Pirayesh, A.E., Seregni, M., Doumeingts, G., Zanetti, C., Westphal, I., & Hans, C. (2018). A Conceptual Model for Product Service System (PSS).

Pirola, F., Boucher, X., Wiesner, S., Pezzotta, G., 2020. Digital technologies in product-service systems: a literature review and a research agenda. Comput. Ind. 123, 103301.

Pirola, F., Pezzotta, F., Cavalieri, S., 2022. Design and engineering of product-service systems (PSS): The SEEM Methodology and Modeling Toolkit. In: Karagiannis, D., Lee, M., Hinkelmann, K., Utz, W. (Eds.), Domain-Specific Conceptual Modeling, Concepts, Methods and ADOxx Tools. Springer International Publishing, Switzerland, p. 2022.

Rapaccini, M., Adrodegari, F., 2022. Conceptualizing customer value in data-driven services and smart PSS. Comput. Ind. 137, 103607.

Reim, W., Parida, V., Örtqvist, D., 2015. Product–Service Systems (PSS) business models and tactics–a systematic literature review. J. Clean. Prod. 97, 61–75.

Romero, M., Guédria, W., Panetto, H., Barafort, B., 2020. Towards a characterisation of smart systems: a systematic literature review. Comput. Ind. 120, 103224.

Sassanelli, C., Terzi, S., 2022. The D-BEST Reference Model: A Flexible and Sustainable Support for the Digital Transformation of Small and Medium Enterprises. Glob. J. Flex. Syst. Manag. 2022 (40171), 1–26. https://doi.org/10.1007/s40171-022-00307-y.

Sassanelli, C., Pezzotta, G., Pirola, F., Rossi, M., Terzi, S., 2019.). The PSS Design GuRu Methodology: Guidelines and Rules Generation to Enhance Product Service Systems (PSS) Detailed Design. J. Des. Res. 2019 (17), 125–162. https://doi.org/10.1504/JDR.2019.105756.

Selic, B., 2003. The pragmatics of model-driven development. IEEE Softw. 20 (5), 19–25.

Sjödin, D., Parida, V., Kohtamäki, M., Wincent, J., 2020. An agile co-creation process for digital servitization: A micro-service innovation approach. J. Bus. Res. 112, 478–491.

Solem, B.A.A., Kohtamäki, M., Parida, V., Brekke, T., 2021. Untangling service design routines for digital servitization: empirical insights of smart PSS in maritime industry. J. Manuf. Technol. Manag.

Trevisan, L., Brissaud, D., 2017. A system-based conceptual framework for product-service integration in product-service system engineering. J. Eng. Des. 28 (10–12), 627–653.

Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strategy Environ. 13 (4), 246–260.

Valencia Cardona, A.M. (2017). An exploration of smart product-service system design: guidelines and insights for design management.

Valencia Cardona, A.M., Mugge, R., Schoormans, J.P., & Schifferstein, H.N. (2014). Challenges in the design of smart product-service systems (PSSs): Experiences from practitioners. In *Proceedings of the 19th DMI: Academic Design Management Conference. Design Management in an Era of Disruption, London, UK, September 2–4, 2014*. Design Management Institute.

Zheng, P., Wang, Z., Chen, C.H., Pheng Khoo, L., 2019. A survey of smart product-service systems: Key aspects, challenges and future perspectives. Adv. Eng. Inform. 42 (April), 100973.

Zou, W., Brax, S.A., Rajala, R., 2018. Complexity in product-service systems: review and framework. Procedia CIRP 73, 3–8. https://doi.org/10.1016/j.procir.2018.03.319.