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Article

A Conceptual Framework for Product Service System (PSS)

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Abstract: To remain competitive in the current market, an enterprise must differentiate itself based on higher value propositions. For this purpose, since improving the product or service performance can reach some limits, one potential solution is to move towards new combinations of products and services. This evolution, called servitization, leads to the generation of Product-Service Systems (PSS). Servitization requires not only a clear understanding of enterprise core business but also a clear vision on the prevailing trends and challenges of PSS development from both business and technological points of view. In addition, the evolution path should be aligned with the enterprise strategy. This paper first highlights the notion of *symbiotic* PSS where Product Systems and Service Systems, and their stakeholders, interoperate seamlessly based on a win-win approach. Then it proposes a PSS Conceptual Framework (PSS-CF) which can be applied in the early stages of servitization to increase the understating of PSS dimensions and to facilitate the prioritization of the servitization investments. The framework dimensions were discussed in several iterations, from both academic and industrial points of view, in the frame of a European research project. Moreover, the applicability of the framework was studied in four different industrial Use-Cases.

Keywords: Product Service System (PSS); Servitization; Productization; Symbiosis; Enterprise Management; Conceptual Framework; Strategic Change;

1. Introduction

Enterprise management is intended “*to design, control and improve the business processes to adapt to the changing business environment …*” [1]. Moving from product-centric businesses towards a service economy is a confirmed change and practicable strategy for manufacturers [2]. Such a movement is originally called “servitization of business” [3]. Servitization, leads to the design and development of Product Service Systems (PSS) where innovative combinations of products and services are realized to increase the market share [4], [5] or sustainability [6]. PSS can be also designed with a *productization* strategy (i.e. service to product) when the enterprise is originally a service provider. Such backward movement is mentioned in [7]. It should be mentioned that productization does not indicate withdrawing from service initiatives, a process referred to as deservitization by [8]. According to [9], PSS has emerged as one of the most important business concepts for industrial organizations.

Regarding the production [manufacturing] system, complexity has been mentioned as a challenge in the development and analysis of such systems [10,11]. PSS not only inherits this complexity but is also involved with the complexity of service related activities. In addition, the nature of PSS indicates the necessity of fast and adaptive responses to customer needs, comparing to traditional product systems [4]. Due to PSS complexity and necessity of high reactivity, despite the benefits of servitization, this strategy is not always adoptable [2]. Managers should be more and more flawless in dealing with such strategical matters [12] while taking proper decisions and actions on the orientation of investments [13]. Therefore, the following research question can be raised: "*how to support enterprise management in the early stages of servitization / productization?*"

In order to resolve the above question, enterprise management can be guided, with methodologies [14] to successfully conduct the servitization [15]. Another possible approach for supporting managers in the servitization process is the analysis of prevailing trends and PSS viewpoints. According to Briscoe et al., researches on servitization can be studied through different lenses (viewpoints) such as value co-creation and collaboration; systems and networks; information and communications technology; and complexity [16]. Such viewpoints are sometimes identifiable in conceptual frameworks [17]. From a generic perspective, a conceptual framework can be designed based on the key dimensions of a subject or the viewpoints that are to be addressed in the study of that subject. Generally, frameworks or models provide simplified representations of complex subjects and increase the knowledge on the new concepts, as well as the prevailing trends and challenges [18].

With a focus on the aforementioned research question, this paper proposes a PSS Conceptual Framework (PSS-CF) which is mainly developed and validated in the frame of a European research and innovation project [19] and its industrial Use-Cases. The methodology adopted for developing this framework is presented in the following section.

2. Research Methodology

As illustrated in Figure 1, this research work was initiated by a preliminary literature review to consolidate the research question. The results underlined "*the lack of conceptual approaches with strategical purpose supporting enterprise managers in the early stages of PSS development*" which is a precision of the initial research question mentioned in the introduction. Consequently, with the objective of developing a PSS conceptual framework, the concept of PSS was analyzed as a whole based on the definitions and classifications proposed in the literature. This allowed identifying the key viewpoints, being potentially the dimensions of the framework. In this context, the viewpoints underline an important characteristic of PSS, a criterion for its classification or a trivial issue in its lifecycle. For instance, a conceptual framework from Business Model viewpoint, to assist with the development of PSS, is proposed in [20].

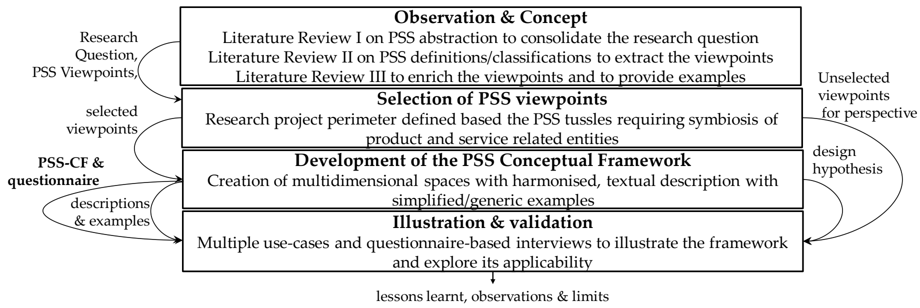

Figure 1. Research methodology

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In the next step of the methodology, the identified viewpoints were synthetized. Each dimension was individually re-studied, according to the literature, to confirm its importance and to provide examples of related research works. The viewpoints were then selected to be included in the PSS-CF considering the perimeter of the research project. The selected viewpoints were structured as a multidimensional space being the backbone of the PSS conceptual framework. The dimensions were also harmonized with four maturity levels, from separated PSS, indicating isolated product and service related entities, to symbiotic PSS, which involves close and long-term win-win relationship between product-service related entities and often dichotomies around these entities. The designed framework was then extended with detail description of the dimensions and layers as well as simplified and generic examples. Eventually, to study and illustrate the applicability of the framework, it was applied, using a dedicated questionnaire, in four industrial Use-Cases with different profiles. The main objective here was to support the analysis of the enterprise strategy on servitization, and to facilitate the prioritization of the innovation, research and development actions. Eventually, PSS-CF was applied in four industrial use cases to validate its dimensions and layers, positioning current and desired positions within each case.

3. Literature review

3.1. PSS conceptualisation, abstraction and modeling

Servitization can be supported by generic or specific conceptualization, abstraction or modelling techniques which reduce PSS complexity [17]. In a recent research work, analyzing several PSS modeling approaches supporting PSS design, the following issues are highlighted (see Table 1): 1) lack of high-level standardization, 2) lack of genericity, 3) specificity of the applications and industrial cases, 4) lack of detailed representation, and 5) high level of granularity [21].

While confirming the issues of PSS abstraction highlighted in [21], we believe that they might be less critical in the early stages of PSS design when servitization is still under strategical analysis or when servitization ideas have not yet become design concepts. In fact, in these stages, the modeling approach should be able to conceptually underline the issues limiting the migration from product / service to PSS. Moreover, it should support decision makers in the analysis of their enterprise strategy and identification of potential improvements achievable through servitization. To clarify the stages of servitization covered by the modeling approaches, while indicating the supported task, step or phase in PSS lifecycle, we performed a complementary analysis of PSS modeling approaches (see Table 1). The results highlighted the research question stated in the "research methodology" section.

Table 1. PSS conceptualization, abstraction and modeling approaches (inspired by [21])

Reference	Year	Approach	Summary	Lifecycle focus
[22] [23]	2006 2010	Integrated Life Cycle	A modeling technique based on service lifecycle (integrating product lifecycle)	Lifecycle management
[24] [25]	2007 2009	Service Engineering Service Explorer	Multi-model framework for PSS design Computer-aided service design	PSS design
[26]	2008	Service-Oriented Modeling Framework (SOMF)	Service–oriented life cycle modeling methodology based on the service–oriented modeling paradigm	Lifecycle management
[27]	2009	IPS² Metadata Model	A metadata reference model for Industrial PSS (IPS²) lifecycle management	Lifecycle management
[28] [29]	2009 2011	Extended/Product Service Blueprint	Enlargement of the classical modeling technique "Service Blueprint"	P-S Integration
[30]	2010	PSS Layer Method	Multi-layer modeling framework to highlight requirements and tasks for PSS design	PSS design (Requirements elicitation)
[31]	2009	SLM (Service Modeling Language) and SML Interchange Format (SML-IF)	Constructs for creating models of complex services and systems, and standard for exchanging service models	PSS design (process modeling)
[32]	2013	Functional Hierarchy Modeling	Modeling technique for PSS functions. Proposition of a novel PSS typology	PSS design (Functional analysis)
[33]	2014	Model Driven Service Engineering Architecture (MDSEA)	Multi-level architecture and methodology for service system design and development	PSS design and development
[34]	2014	Extended Product Business Model	Methodology to integrate Extended Product (EP) into the business models	Business Modeling
[35]	2016	PSS Multi-Views Modeling Framework	A multi-view modeling framework combining product-oriented and service-oriented engineering.	PSS design
[36]	2016	PSS conceptual structure	A conceptual structure depicting the situation of literature in the analysis of economic, environmental, and social impact of PSS	PSS evaluation
[20]	2017	PSS business model conceptual framework	A conceptual framework to support PSS development from business model perspective	Business Model

3.2 *PSS definitions and classifications*

3.2.1. PSS definitions

In the recent study of Oliveira et al., a comprehensive bibliometric analysis of the PSS research field is performed which provides an understanding on this domain [9]. Considering this analysis, the PSS definitions proposed by the top five papers regarding citation are analyzed here in addition to the definition proposed by MSEE (Manufacturing SErvice Ecosystem), SusProNet (Sustainable Product-Service co-design Network), and PSYMBIOSYS (Product-Service sYMBIOtic SYStems), which are examples of European initiatives in servitization context. The analyzed definitions highlighted that PSS can be addressed from the following viewpoints.

PSS can be considered as an economic activity with known market, business model, selling point and economic value [37,38,39,40]. PSS is business oriented and there is a customer willing to pay for the P-S and participating in the business model. PSS separates business success and economic growth from mere product sales.

Product and service related systems and elements are in interaction & integration within a PSS [37,39,40,41,42,43,45]. The outcome is in fact a mix of tangible products and intangible services which should interact jointly and symbiotically. In a PSS the service is not necessarily an "add-on" to the product. Product and service can form an integrated solution while related entities have different relative importance [e.g. in terms of resources allocation] and one can dominate the other. For instance, a PSS can be service-oriented or product-oriented [44]. No matter the relative importance of product and service related entities, there should be a *symbiotic* (win-win) relation between them to fulfill specific customer needs with higher added values comparing to isolated products and services [45].

PSS is designed, combined and provided to the customer to fulfil its needs with higher value proposition comparing to isolated products and services [37,39,40,41,42,43]. Therefore, the benefits of the PSS for the customer comparing to mere products or services should be clearly defined. Sometimes the service contributes/forms the major part of the provided value.

Organizational aspects such as configuration and type of internal and external resources are important issues in PSS [37,38,41,42,43]. Different types of supports should be combined to product and service lifecycles. PSS is usually developed within a network of enterprises due to the necessity of the involvement of stakeholders with diverse competences and functions. It also requires an infrastructure supporting the usage of the product and the delivery of the service.

PSS contributes to sustainability [38,41]. Environmental impacts are lower than traditional business models, e.g. when a service supports the sharing of the physical products such as vehicles. In fact, servitization might decrease the usage of resources and consequently the negative manufacturing impacts on the environment.

Table 2. Synthesis of PSS definitions

Reference	Year	Viewpoints				
		Economic Activity	Interaction & Integration	Value proposition	Organizational aspects	Sustainability
[37]	1999	Marketable	Jointly fulfilling	User's need	A company/alliance	-
[38]	2002	Business models	-	-	Networks, infrastructure	Environmental impact
[39]	2003	Selling	Jointly fulfilling	Client demands	-	-
[40]	2004	Economic value	Jointly fulfilling	Customer need	-	-
[41]	2007	-	Integrated offering	Value in use	Knowledge, expert	Environmental impact
[42]	2004	-	Jointly fulfilling	Value proposition	Network, infrastructure	-
[43]	2012	-	Interrelated components	Customers	Resource combination	-
[45]	2017	-	Jointly & symbiotically	Customer need	-	-

3.2.2. PSS classifications

In the next step of the literature review, seeking to identify PSS viewpoints, various classifications were studied. These classifications are summarized in Table 3. While initial PSSs were of the type "product-centered", in the course of time the services became a more important and self-reliant part of the product-service combination. In some cases, the physical product was even aligned

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to a service or parts of it were replaced by services, e.g. cloud services that replace hardware storage capacity. This development led to enhanced value proposition for the customer and to better options for differentiation in comparison with competitors.

Table 3. Synthesis of PSS classifications

Reference	Year	Viewpoint
[46]	2000	Contribute to sustainability
[47]	2001	Evolution of Product Service Systems, Value proposition
[40]	2004	Product ownership, Provider's role in the value production, Business Model
[48]	2011	Product and service engineering,
[49]	2011	Relationships between product and service design and ICT are used to analyze the data.
[50]	2012	Relationship between products and services (duality vs. unity), Products Ownership, Role Technology
[32]	2013	Level of integration and performance orientation of the dominant revenue mechanism within the PSS
[51]	2016	Product type (Durable vs Capital goods), Service type

3.3. Synthesis of PSS viewpoints

The PSS viewpoints, extracted from the definitions and classifications, were synthetized in seven categories while enriching them with individual and complementary literature review.

Business model viewpoint, depicting the level of integration of product and service business models in a company: This viewpoint includes several others such as economic activity, marketability, selling point, ownership, and value proposition. Vargo et al. address PSS from this viewpoint. They consider that the manufacturers must be able to clearly define the actual product or service and their value proposition for the customer since it is the core purpose and central process of economic exchange [52]. BM is a confirmed viewpoint and issue in PSS context [34]. As the product is not adapted to the new BM, it shows the need to adopt a holistic strategic approach to service implementation [53]. Furthermore, according to some interviews, it is considered that existing contracting practices did not reflect the new service BM [53]. Its actual relevance is partially expressed by [54], when stating that the complexity of service BM implementation would appear to lie at the heart of this 'service paradox' (i.e. increasing revenues, though decreasing the actual profit). Hence, the integration of business innovation into the existing business environment is crucial.

Innovation Openness viewpoint, defining the perimeter of the PSS ecosystem, as well as the relations of different stakeholder during PSS development: This viewpoint is also related to ecosystem, collaboration, network, organization, alliance, and stakeholders. According to Lindberg and Nordin, the following misunderstanding can occur in PSS innovation: "*Who's responsible for what when things fail [during or after the PSS development]? [As a trigger of innovation] It is very costly to solve all the problems of responsibilities when things fail*." [7]. The relations between the stakeholders in PSS innovation depends on their strategy and openness of the innovation. The concept of Open Service Innovation has been studied in [55].

Dependency viewpoint, focusing on the strength and the scope of the interaction between the PLM and SLM: Viewpoints such as product-service correlation, co-creation and influence are also considered here. Correlations, between the product and services, and by extension the activities producing and delivering them, can be detected all along the P-S lifecycles. It can be about resource allocation, synchronization of activities etc. Service design should cope with the functionalities provided by the product coupled with that service in a PSS. Therefore, there is a strong need for interactions in P-S lifecycles [56] in both directions. Products are not always optimized to be coupled with services. Thus, it is required to improve the product or service design process and its equipment, in respect to each other, in case of servitization [53].

Topology viewpoint, representing the level of integration between real and digital world elements: Other viewpoints such as integration, configuration, and infrastructure, are also relevant here. From this viewpoint, the relation between products and services within a PSS can correspond to different configuration of cyber (so called digital world) and physical (so called real world) parts. "*Cyber-Physical Production Systems (CPPS) foster new processes and production methods for reducing "time to market", waste and failures, as well as improving quality and cost effectiveness.*" [57]. From an ICT perspective, tools and platforms can be designed and proposed to the customer as centralized vs. integrated real-digital platforms.

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Interoperation viewpoint, addressing the exchange and management of data, information, knowledge and process within the PSS: Interaction, information and communication also correspond to this viewpoint. The development of interactions between product and service related activities can be challenging when actors from various fields of expertise or with different types of resources, must exchange information [58, 59]. In addition, it is crucial to encompass other types of knowledge, rather than the technical knowledge as through time the enterprise learns from its services and gains knowledge (e.g. learning from the maintenance services of a machine) [56]. There is a strong need for information exchange between service and product staff [56]. To resolve these challenges, solutions in the form of collaboration tools or interoperability improvement methods are required [60]. This issue in PSS context can be addressed more generally by studying the exchanges between the product and service systems in terms of data, knowledge and process sharing.

PSS can be studied under Sustainability viewpoint that addresses the environmental impacts. Such impacts are usually lower than traditional business models when servitization decrease the usage of resources and consequently the negative manufacturing impacts on the environment. Annarelli et al. provided a conceptual structure, from this viewpoint, depicting the current situation of literature dealing with the analysis of PSS [36]. A method for sustainability assessment of PSS is proposed by Allais & Gobert while highlighting the socio-economic and environmental context and specific issues linked to small appliances [61].

4. Design of PSS Conceptual Framework (PSS-CF)

4.1. Selection of viewpoints

To design the PSS-CF, among the viewpoints extracted from the literature, we first selected the ones conforming to the scope of the aforementioned European research project which addresses mainly PSS tussles requiring symbiosis of product and service related entities. Therefore, sustainability viewpoint (environmental issues) was excluded while PSS modelling was added due to its importance, previously mentioned in the introduction and methodology sections. This paper is indeed founded on the necessity of PSS abstraction techniques in the early stages of servitization. The modelling viewpoint is also extended to simulation englobing PSS test and evaluation aspects since simulation is necessary for providing assessments of the PSS performance in terms of dynamicity and behavior since models provide only a static abstraction of the system [18].

4.2. Structuring the viewpoints as the framework dimensions

The selected viewpoints, called dimensions in PSS-CF, were then structured as a multidimensional framework covering two domains (i.e. business and technology) focusing on the main domains of design, development and innovation:

- *Technology-driven*: In this domain, servitization or productization is mainly focused on the type and role of the technology used in the P-S lifecycles from ideation, to design, production and delivery. In addition, the PSS is often "technologically" supported in the provision of expected value to customer.
- *Business-driven*: In this domain, servitization or productization is mainly focused on the business aspects, such as enterprise network or collaborations. Moreover, "business benefits and risks" of the PSS for different stakeholders (e.g. supplier and customer) are studied.

The Technology and Business domains are correlated; each one might constraint the other. For instance, the cooperation strategy (as a business condition) in enterprise network might limit the choice of suppliers providing the product-service technology.

The framework dimensions are grouped around the above domains while forming a 2x3D space (see Figure 2). The link between these two spaces is stablished through two parallel dimensions (i.e. P-S Topology and P-S Business Model) as the core of the framework since the focus of both dimensions is on the different configuration / combination of product-related or service-related entities (e.g. lifecycles, processes, resources, etc.).

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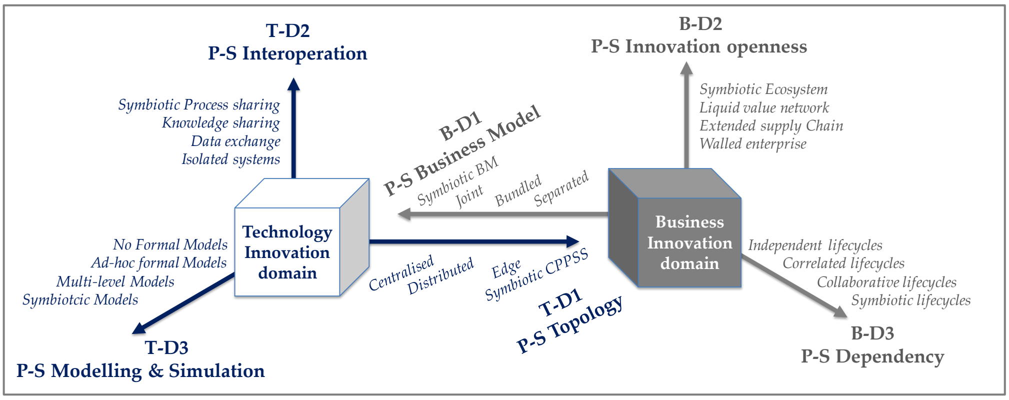

Figure 2. Global view of the Symbiotic PSS Conceptual Framework (PSS-CF)

4.3. Symbiotic maturity levels

To have a harmonized structure for the framework, four levels were defined, for each PSS-CF dimension, corresponding to different degree of intensity / maturity of the relation between the product [system] and service [system] within a PSS (see Table 4):

1. *Disjoint*: for this configuration, there is no link between the product-related or service-related entities all along the product and service life cycles.
2. *Linked*: for this configuration, some ad-hoc or short-term links between the entities can be identified. However, there is no common objective. For instance, a resource, in product lifecycle, can be also used in service lifecycle on demand or for a short period of time.
3. *Connected*: for this configuration, we can identify several links between the entities. The links are established with common objectives and based on a collaborative approach. However, the collaboration is not always in favor of both sides (i.e. product and service). For instance, a resource can be shared between product and lifecycles but it can work only on one side at a time with predefined priority.
4. *Symbiotic*: The last configuration, as the highest maturity level, indicates a close and long-term win-win relationship between product-service related entities, which often generate dichotomies. For instance, resources can be shared between the lifecycles (P-S) and the assignment is optimized to support both lifecycles.

Table 4. Dimensions and levels of the Symbiotic PSS Conceptual Framework

	Business Innovation domain			*Technology Innovation domain*		
ID	B-D1	B-D2	B-D3	T-D1	T-D2	T-D3
	Business Model	Innovation Openness	Dependency	Topology	Interoperation	Modeling & Simulation
Disjoint	Separated Business Models	Walled Enterprise	Independent Lifecycles	Separated Cyber-Physical PSS	Isolated Systems	No Structured Method
Linked	Bundled Business Models	Extended Supply Chain	Correlated Lifecycles	Distributed Cyber-Physical PSS	Data Exchange	Ad-hoc Structured Method
Connected	Joint Business Models	Liquid Value Network	Collaborative Lifecycles	Edge Cyber-Physical PSS	Knowledge Sharing	Multi-level Models
Symbiotic	Symbiotic Business Model	Symbiotic Ecosystem	Symbiotic Lifecycles	Symbiotic Cyber-Physical PSS	Symbiotic Process sharing	Symbiotic Models

5. Description of PSS Conceptual Framework

As mentioned in the previous section, PSS-CF is a multidimensional space constructed based on the key dimensions (viewpoints) to be addressed in PSS lifecycle. In this section, these dimensions and their layers are presented based on [19] in a more descriptive and illustrative way.

5.1. P-S Business Model dimension (B-D1)

Business Model (BM) dimension of the PSS-CF offers four levels all of which differentiate the relation between products (or established services) and (new) services. The levels are (see Figure 3):

- *Separated*: At this level, the enterprise has separated BMs for products and services where they are offered and sold, sometimes to different customer segments, with separated value propositions (e.g. car and repair services or insurance). The revenue streams for both are independent which means the customers should pay for each product and service separately. Sometime there are even separated invoices. Usually this implies that the key activities regarding the products and services and the required key resources are separated as well.
- *Bundled*: At this level of P-S BM the enterprise offers and sells its customers a bundle of products and related services. This is often done in addition to offering the components separately. In many cases, the customers pay one price for the bundle that is usually lower than for its single components. The bundle products and services might address the same customer and the customer perceives a "one-face-to-the-customer" approach [62] where all the customer's needs can be met by a single organization. Typical examples are installation, training and maintenance that can be ordered as "ad-on(s)" to the product.
- *Joint*: At this level, the value propositions of the products and services are still visible as separate components. However, the enterprise offers them only as a combined package. The customers cannot have one without the other, e.g. a product and an extended warranty or a corresponding service hot-line. Other examples are software-solutions where the customers should book a maintenance service contract. Renting can be also considered at this level since the products and services are not separable where the enterprise sells services while renting/leasing products.
- *Symbiotic*: The symbiotic BM represents the highest level in this dimension. The customer perceives one integrated value proposition and pays one price for it. The value proposition can be based on several different product or service components that could change from case to case. For the customer, it makes usually no sense to differentiate between the single components. If, for instance, the customer pays for the transport from A to B in a defined time it is generally not very important if this is achieved by bus, train or taxicab (if he does not have to change the means of transportation too often with long waiting times). So, the different components of the PSS, form a "community", supporting each other in a symbiotic way. This should be considered in the BM, as well. It is important to share the economic benefits and risks between the contributors in an appropriate way. These benefits can be achieved by increased sales based on the network [or symbiotic] [63]. This means the more users apply the same standard of products or services the more the added value will grow.

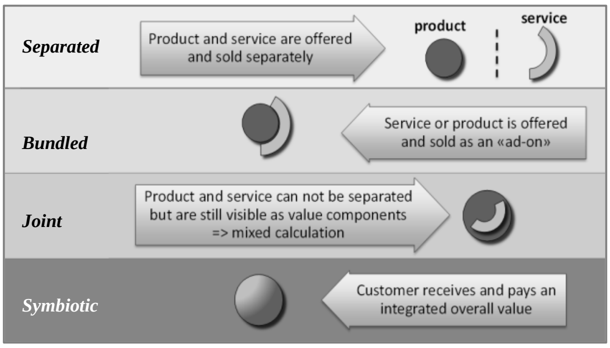

Figure 3. Levels of the "P-S Business Model" dimension

5.2. P-S Innovation Openness dimension (B-D2)

In the Product and Service lifecycles, the stakeholders can have different degrees of involvement. This also defines the perimeters of the PSS ecosystem:

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- *Walled Enterprise*: PSS lifecycle is managed by one enterprise. Innovation is closed and is done internally.
- *Extended Supply Chain*: Several enterprises collaborate in PSS supply chain for producing, delivering and innovating the product and service. Here, PSS lifecycle is in collaboration with Supply Chain. This level looks into traditional hierarchical tier-based chains.
- *Liquid Value Network*: The collaboration is not only in supply chain but also in PSS value chain. In this case, Customers and Consumers are actively involved in PSS Value Chain and P-S innovation process. Here, the term "liquid" indicates a border-less enterprise looking into peer-to-peer value networks (virtual enterprise). Liquid enterprise model proposed within OSMOSE European research project represents an example of this level of P-S Innovation Openness.
- *Symbiotic Ecosystem*: This indicates several partners around PSS lifecycle and P-S innovation process, including suppliers, manufacturers, service providers, research and innovation entities and even the government. Here, a PSS ecosystem is formed.

5.3. P-S Dependency dimension (B-D3)

This dimension indicates the way the PSS BoL, MoL and EoL activities (design, engineering, usage and recycling) are conducted and how actors (designers, engineers, manufacturers, users etc.) interact with each other:

- *Independent Lifecycles*: it indicates different teams and independent projects and processes for product and service.
- *Correlated Lifecycles*: it happens when we still have different teams but there is a kind of relation between them. The relation can be through communication, shared resources, and feedback loops or rendezvous points. Despite such links, the strategical or tactical objectives are not common.
- *Collaborative Lifecycles*: it requires common and single objective for product and service design and development. In this case, the development teams are mixed and they share their resources but also, they support each other all along the process through co-operative work.
- *Symbiotic Lifecycles*: it involves open and agile teams with frequent interactions. A single Product-Service team can be formed for designing products or services.

5.4. P-S Topology dimension (T-D1)

This dimension depicts the alternative configurations of a PSS according to the degree of connection between Physical, so-called "*Real-Word*", and Cyber elements, so-called "*Digital- World*":

- *Separated Cyber Physical* where PSS centralized cyber components are not interconnected with the Physical ones; Physical product is just as a (passive) source of data.
- *Distributed Cyber Physical* where PSS distributed Cyber components can communicate with Physical ones by means of intermediate center. Physical product can provide and store data.
- *Edge Cyber Physical* where PSS Cyber and Physical components extensively communicate. Physical product can collect, store and filter data. Wearable devices for Medical Monitoring represent a good example of Edge Cyber Physical PSS.
- *Symbiotic Cyber Physical* where PSS Cyber and Physical components are integrated. Physical product can collect, filter and store data as well as to send alarm and notifications. CPS for predictive maintenance is considered as one possible example of this level.

5.5. P-S Interoperation dimension (T-D2)

In PSS-CF there are two dimensions that consider the cooperation and exchanges among partners; one is focused on the business innovation side, which is called "P-S Innovation Openness" dimension (see section 5.2), and the other one is focused on the technical innovation side, which is called "P-S Interoperation" dimension. Generally, the technical dimension of interoperation provides the means for cooperative business processes, especially when it comes to open innovation processes.

It emphasizes on the data, information, knowledge and process exchanges and their management between the partners or PSS components. This means that "partners" do not necessarily have to be different, legal independent enterprises but could also be different departments or other organizational units within one enterprise.

The levels regarding the technical dimension of "Interoperation" are:

- *Isolated Systems*: In this situation, Product and Service Lifecycle Management (LcM) IT are separated. In fact, individual information systems and databases exist for product and service.
- *Data Exchange*: This happens when Product and Service LcM IT (mainly information systems) can communicate with each other through data exchanges. Here, interoperability between systems reaches a technological level.
- *Knowledge Sharing*: In this case, communication between Product and Service LcM IT goes beyond simple data exchange. In fact, processed and reasoned data, knowledge or sentiment can be also exchanged. There are broad options to not just exchange data but to get access to data. Here, the IT systems are interoperable technologically and semantically.
- *Symbiotic Process sharing*: When Product and Service LcM IT use a single data model and are fully interoperable while sharing processes, they are considered at this level.

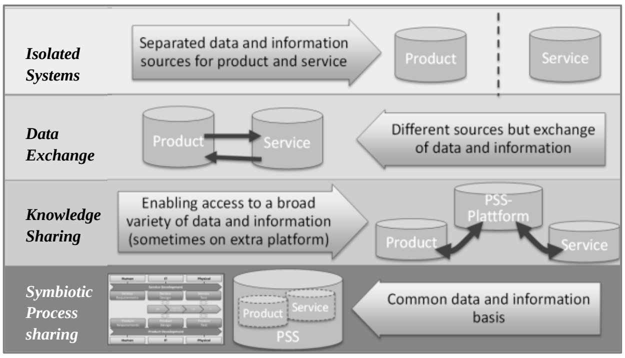

Figure 4. Levels of "P-S Interoperation" dimension

5.6. P-S Modeling & Simulation dimension (T-D3)

Product-Service related models may exist in different forms (e.g. product or service data model, physical or business process model, system model, enterprise architecture etc.) with divers modeling supports. The Modeling & Simulation (M&S) dimension highlights the usage of these models, modeling, simulation or test supports (e.g. formalisms, languages, and tools), and the methodology behind them, in P-S lifecycle:

- *Models with no structured method*: This level corresponds to a lack of M&S support with structured methods or standard concepts, for representation of product-service related objects. Some graphical representations or models might exist, with no commonly accepted structure, just to present a simplified vision of an object. In such models, the links between product and service are not formally described. In addition, models are not simulation-ready.
- *Ad-hoc models with structured method*: This level indicates the existence of M&S support for products or services with known, shared, standard or structured couple of modeling languages / techniques. At this level, models can be simulation-ready or dynamic but there is no link between product simulation and service simulation. Unified Modeling Language (UML) which is a general-purpose modeling language in the field of software development [64] and Graphs with Results and Actions Inter-related (GRAI) which is a structured modeling method of Enterprise modeling [65]) can be mentioned as examples.
- *Multi-level models*: This level conforms to the availability of M&S support with different abstraction levels in the P-S value chain. The levels can correspond to different granularity or different perspectives on the same object; from global to local, from business to IT, or from

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static to dynamic. In some modeling languages such as IDEF [66], process models can be elaborated with a bottom-up or top-down approach to illustrate a process at its global to local levels based on the granularity of the activities. As another example, Model Driven Service Engineering Architecture (MDSEA) [33], developed based on Model Driven Architecture [67], considers different linked layers with business or technological views on the [product-service] system. At this level of modeling, models can be simulation-ready or dynamic while there is a link between product simulation and service simulation but not in a joint or optimized way.

- *Symbiotic models*: This level indicates the models or M&S support in the value-chain that bridge product and service related elements (e.g. lifecycles). For instance, a symbiotic process models can include both design of product and service as well as the interactions (information or physical flows) between the two design processes. Therefore, Product and Service lifecycles are usually represented in a single model. A unified decisional model for controlling P-S lifecycle is proposed in [17]. At this level of modeling, models can be simulation-ready or dynamic while the simulation is done in a joint way on the product and service to find the optimized scenario

6. Case Study

According to Yin, one of the situations in which a case study is a preferred research strategy is when "how" or "why" questions are being posed [68]. In this research work, the objective of the case study is, on the one hand, to illustrate how PSS-CF can be applied as a strategical support in servitization process, and on the other hand, to explore and verify its applicability in industrial environments. Respectively, the conducted case study can be categorized as descriptive [illustrative] and exploratory [68]. Different steps of the case study are illustrated in Figure 5.

Multiple case studies ensure a higher generalizability of results, limiting bias related with company's characteristics [68,69]. Therefore, to illustrate and verify the applicability of the PSS-CF, four cases with different industrial environments, were investigated. The selected cases are manufacturing companies undertaking servitization process in the following domains: Textile (Use-Case 1), Office furniture (Use-Case 2), Cutting Tools (Use-Case 3), and Use-Case 4 (Cabin Video Surveillance).

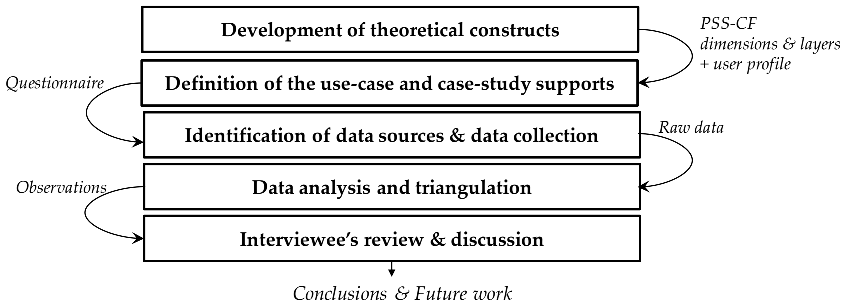

Figure 5. Case study methodology

The main objective of using PSS-CF was to obtain a preliminary evaluation of the Use-Cases' position in PSS context, before and after a research project. As a preliminary step, theoretical constructs and concepts were derived from the literature review, mainly consisting here in the PSS viewpoints and layers as well as related concepts which guided the design of a questionnaire for interviewing Use-Case representatives (see Tables A1 and A2 in Appendix A, respectively for the questions and an example of Use-Cases' answers). Yet, authors investigated firms' reports to triangulate data from these structured interviews, thus ensuring a higher reliability of findings [69,70]. Based on data collected from these sources, an initial PSS-CF was drawn for all the four cases. Lastly, initial PSS-CF propositions were shared with interviewees to get feedback and to reach a common agreement on the concepts.

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6.1. Expected Evolution

In this section, the objective is to illustrate a possible application of PSS-CF for the analysis of enterprise PSS strategy. From a generic point of view, the priority of a topic in the enterprise strategic actions (e.g. a financial investment, participation in a research project, etc.) can be defined based on different parameters such as:

- Expected evolution, indicating the gap between the initial and desired position of the enterprise. A topci with higher expected evolution can be prioritized in the servitization / innovation strategy.
- Probability of evolution, indicating to what extend a desired position is possible to reach. A topic with higher feasibility of evolution might be prioritized in the innovation strategy.
- Return on Investment (RoI), indicating the profit of the evolution considering the required investments and usage of resources (e.g. financial). A topic with high RoI should be prioritized in the servitization / innovation strategy.

Here, the focus of the case-study is on the expected evolution while the research project (at the origin of this paper) is considered to be a driver for servitization. To study the expected evolution, at first, the position of Use-Cases in the beginning of the project (AS-IS position) and the position to be reached by the end of the project (TO-BE position) were projected on the PSS-CF (see Figure 6).

Considering the gap between the initial and desired positions of a Use-Case, its expected evolution in a dimension can be qualified as:

- Negative gap or backward evolution which is logically not desired and should be further investigated.
- Zero gap or no evolution where the highest maturity level is already reached
- Single, double and triple gaps where the expected evolution is respectively low, medium, and high.

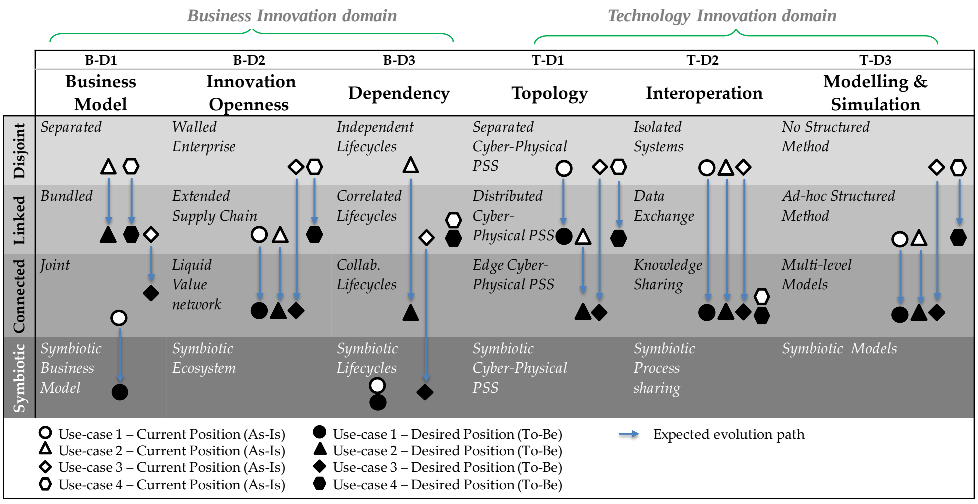

Figure 6. Use-Cases' current and desired position in PSS Conceptual Framework

Considering the results of Use-Case positioning in PSS-CF, it can be observed that (Figure 6):

- Use-Case 1 is mainly willing to move from an "extended supply chain" to a "liquid value network" which indicates moving from traditional hierarchical tier-based chains to border-less enterprise looking into peer-to-peer value networks and active involvement of customers and consumers.
- As a part of Use-Case 2 innovation strategy, the enterprise is mainly willing to move from linked to collaborative P-S lifecycles where the design teams are mixed and share their resources. Additionally, they support each other all along the process through co-operative work.

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- Use-Case 3 requires moving from "isolated systems", where individual P-S information systems and data bases exist, to "Knowledge Sharing systems", where processed and reasoned data, knowledge or sentiment can be exchanged between P-S information systems.
- As a part of the innovation strategy, Use-Case 4 is willing to move from "Separated" to "Bundled" in the BM dimension. Initially this Use-Case has handled services generally independent from the initial product, the video surveillance system. As a result, the Use-Case considers an innovation path for the new PSS that starts with services as an "add-on" to the current product. Use-Case 4 also intends to apply "ad-hoc modeling & simulation with structured method", which indicates the existence of models for products or services with known and standard M&S languages with structured supports. Therefore, the enterprise confirms an investment in this dimension that should be studied in its innovation strategy.

6.2. Relative importance

In the second analysis, to verify the results of the evaluation of the expected evolution, mentioned in the previous section, Use-Cases were directly investigated to define the relative importance of a PSS-CF dimension. The relative importance is related to the enterprise willingness to study or invest in a dimension within a servitization project. It can be low, medium, or high which are respectively quantified from 1 to 3 (see Figures 7 to 10).

In the following, some observations are formulated for each Use-Case considering the coherence of the evaluated "expected evolution" and ""relative importance" of the dimensions. It should be noted that Use-Case position, in the beginning or end of project, positioned in "disjoint", "linked", "connected", or "symbiotic" level of PSS-CF dimensions (see Figure 6), is respectively quantified from 1 to 4.

6.3. Expected evolution vs. Relative importance

In USE-CASE 1, it is observed that there is a coherence between the "relative importance" and "expected evolution" (see Figure 7). For instance, "Innovation Openness" and "Interoperation" dimensions are selected as highly studied (scale 3). In other words, the Use-Case intends to focus more on them. At the same time, it expects to evolve in these dimensions, particularly in the P-S Interoperation since there is a gap between the position in the beginning and at the end of the project.

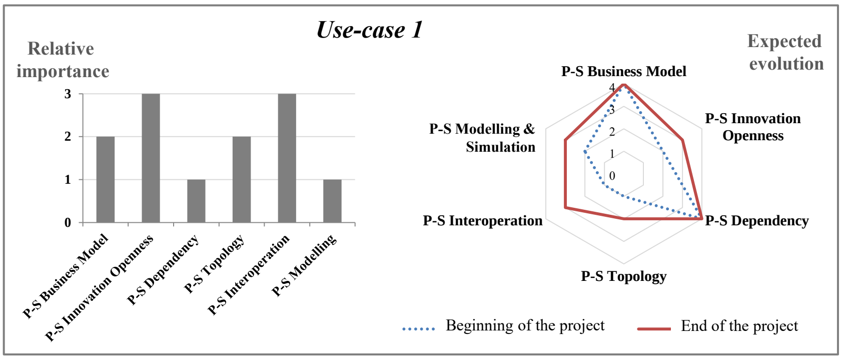

Figure 7. "Relative importance" & "Expected evolution" in USE-CASE 1

In Use-Case 2, it is observed a slightly incoherence between the "relative importance" and the "expected evolution". On the one hand, USE-CASE 2 mainly focuses on "P-S Innovation Openness" and "P-S Interoperation" as they have been selected as highly studied (scale 3). On the other hand, the greatest evolution within the project is expected for the "P-S modeling" and "P-S interoperation" dimension. This can be explained since the Modeling dimension can be considered a supporting competence for properly addressed both P-S Innovation Openness and P-S Topology. In other words, advanced modeling tools and skills within the company will ensure huge benefits in dealing the other two dimensions.

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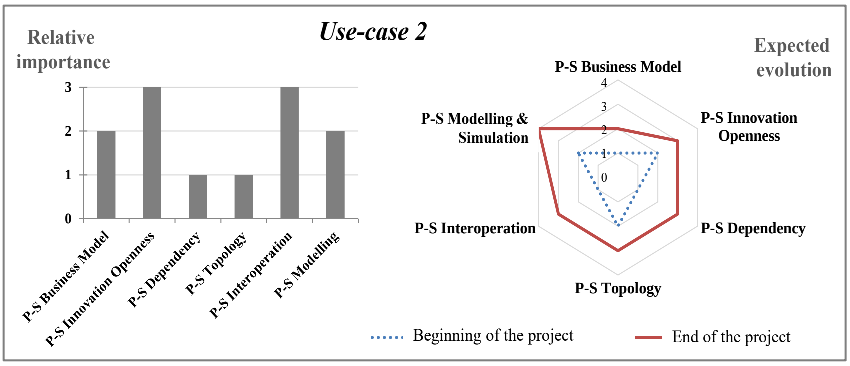

Figure 8. "Relative importance" & "Expected evolution" in USE-CASE 2

In Use-Case 3, it is observed that the relative importance and expected evolution are almost coherent. USE-CASE 3 focuses mainly on "P-S Dependency" and "P-S Interoperation", so that these two dimensions are selected as "highly studied" (scale 3) and considerable development are expected for them within the project. From a generic point of view, USE-CASE 3 shows the largest overall expected evolution from the beginning to the end of the projects among the Use-Cases.

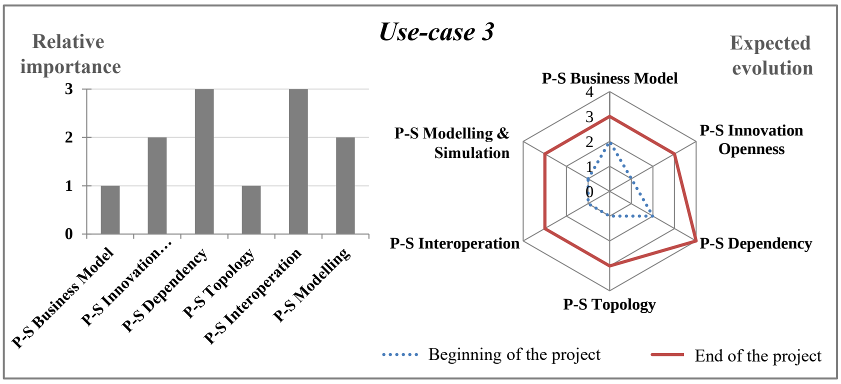

Figure 9. "Relative importance" & "Expected evolution" in USE-CASE 3

In Use-Case 4, it is observed that the relative importance and expected evolution are almost coherent. "P-S Business Model" and "P-S Topology" are identified as the "highly studied" (scale 3), meaning that USE-CASE 4 is focusing more on these dimensions. These dimensions show the lowest value of company characterization at the beginning of the project (Level 1, respectively "Walled Enterprise" and "Separated Cyber Physical"). Therefore, larger room for improvements can be considered for them; as confirmed by USE-CASE 4 expected status at the end of the projects (Level 3 for both the dimension).

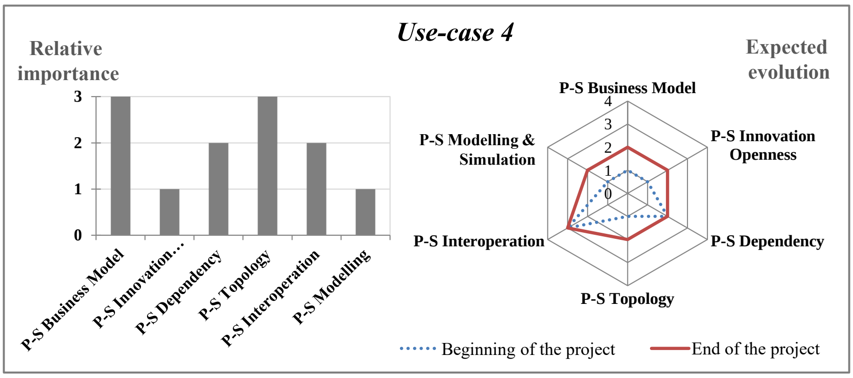

Figure 10. "Relative importance" & "Expected evolution" in USE-CASE 4

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6.4. Comparative analysis of Use-Cases

From a global perspective, Use-Cases show a higher focus on "P-S interoperation", which has been indicated almost "highly studied" (2.75) (See Figure 11). Nonetheless, it is observed that "P-S Dependency" is the dimension with the largest expected evolution within the project (from 1.5 to 3), followed by "P-S Interoperation" and "P-S Modeling" (from 1.5 to 3). However, at the end of the project, characterization of the Use-Cases along the six dimensions will be extremely balanced, ranging from 2.5 ("P-S Topology") to 3 ("P-S Interoperation" and "P-S Modeling").

The four Use-Cases showed that servitization process asks for a step beyond the disjunction of product and service in each dimension. This evolution appears particularly fierce in P-S interoperation, since companies should establish regular and structured knowledge exchanges between product and service businesses (Level 3 – "Connected"). Furthermore, only "P-S Dependency" and "P-S Business Model" present cases willing to reach "Symbiotic" level in the To-Be, respectively Use-Case 1 and Use-Case 3.

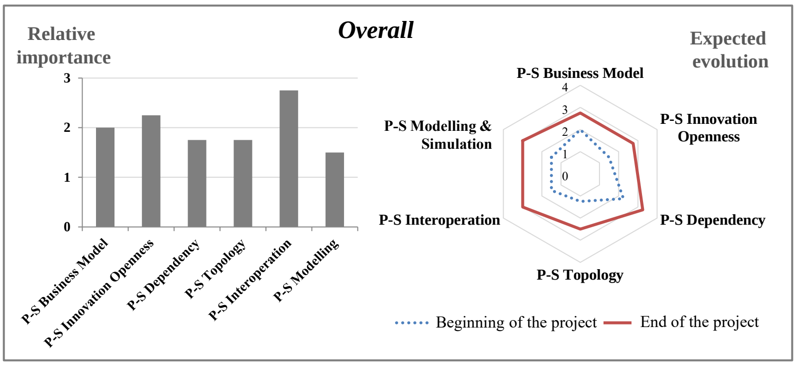

Figure 11. Overall "Relative importance" & "Expected evolution"

In another overall analysis, the observations are based on the alignment between the framework dimensions and supports provided by the project, i.e. knowledge increase, structured methods, and IT Tools and platforms (See Figure 12). In other words, the analysis on how the Use-Case intends to improve this dimension (moving to a higher level) with the project support. The project supports Use-Cases in improving their positioning in almost all the dimensions (average 5.5 out of 6). On average, the project IT Tools and platforms help companies in coping with almost five dimensions while the project provides structured methods for almost three dimensions.

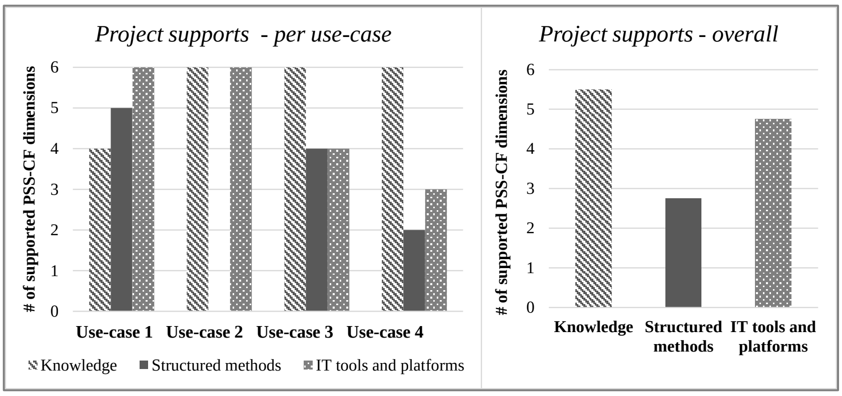

Figure 12. project supports according to the Use-Cases

By focusing on single Use-Cases, it can be observed that supports provided by the project vary. In USE-CASE 2 for example, the project widely provides relevant knowledge increase and IT tools, while structured methods are not relevant for improvements along the six dimensions. On the contrary, USE-CASE 1 heavily relies on structured methods for improving five out of six dimensions.

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7. Discussion and conclusions

The main objective of this paper is to support the researchers, working in PSS context, or enterprises, willing to move towards servitization / productization, with a conceptual reference and a theoretical ground called Symbiotic PSS Conceptual Framework (PSS-CF). The focus is on the early stages of PSS development. PSS-CF, which is a multidimensional space, was designed based on the current prevailing dimensions of PSS development while emphasizing the symbiosis of product and service related entities all along product-service lifecycle. In the current market, it is utmost important to go beyond traditional PSS through creation of symbiotic ones where the benefits and risks are shared between the contributors in an optimized way.

For validation purposes, the results were discussed in several iterations with research and industrial experts in the frame of a European research project called PSYMBIOSYS. This allowed ensuring a preliminary validation within the project consortium as a pilot community which should be then extended. Moreover, to verify the applicability of PSS-CF, it was studied with four industrial Use-Cases through questionnaire-based interviews and firm's report. This multiple case-study approach allowed positioning the Use-Cases along each dimension of the framework. It was mainly observed that:

i. Having understood each dimension, Use-Cases were able to define their current and desired positions (expected evolution) where the passage between them indicates their servitization path.

ii. The relative importance of dimensions and the expected evolution in each dimension are globally aligned in the Use-Cases. Misalignments require further investigation to ensure the coherence of investments for servitization with enterprise strategy and priorities.

iii. Use-Cases indicated higher expected evolution in "P-S Dependency" dimension which could be explained in lights of Transaction Cost Economy [71, 72]. Strategical shift towards a PSS, increases the actors involved as well as the number of interactions required, so that higher transactional costs might occur. Particularly, shift to a more extensive exchange of information is an attempt to cope with this higher complexity, reducing potential asymmetries within the P-S ecosystem.

iv. Use-Cases consider "P-S interoperation" highly important. This could be explained according to Resource Based View (RBV) theory where the servitizing company wants to optimize bundle of Product and Service by exploiting synergies between resources. In RBV, a company evaluates its resources, capabilities, and plans for maximizing long-term competitiveness [73,74,75].

In terms of future research, PSS-CF can be exploited with a survey through collaboration with industrial or research communities such as European PSS cluster. This action allows performing a further validation of the framework, enrichment of the concepts with additional examples, and probably inclusion of new dimensions (e.g. sustainability). The hypotheses in the design of the questionnaire (e.g. equal relative importance of the dimensions) and quantification of the results will be also further studied to have a better evaluation of enterprises' servitization strategy. Adaptation of PSS-CF to the cognitive limitations and Human conditions of enterprise managers is another perspective axis of this research. Few researchers have considered this aspect beforehand in the conceptualization behind the proposed modeling approaches.

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Author Contributions: All authors have contributed to the intellectual content of this paper. A. Pirayesh conducted the writing of the paper. S. Gusmeroli was at the origin of addressing PSS from different viewpoints and levels. A. Pirayesh and M. Seregni performed the literature review with the support of G. Doumeingts, I. Westphal, and L. Gonzalez. A. Pirayesh and G. Doumeingts designed the initial structure of PSS-CF which was then consolidated with the support of M. Seregni and S. Gusmeroli. The naming and definition of concepts (e.g. framework dimensions and levels) were discussed and decided by all the co-authors. A. Pirayesh and M. Seregni designed and conducted the case-study with the support of C. Hans, M. J. Núñez, A. Canepa Eugenio, A. Laskurain, as Use-Case representatives. C. Hans and M. J. Núñez revised the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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Appendix A

Table A1. PSS-CF questionnaire (simplified version[1])

Relative importance of the dimensions
Q1. Which dimension is (will be) studied more in your company? *
Position of the Use-Case in a dimension before the project
Q2. How would you characterize "Dimension X" of your company at the beginning of the research project?
Position of the Use-Case in a dimension after the project
Q3. How would you characterize "Dimension X" of your company at the end of the research project?
Project supports for the Use-Case in each dimension
Q4. How does the research project support you in analyzing and developing "Dimension X"?
** this question was asked separately for each domain (business / technology)*

Table B1. Example of answers to the questionnaire regarding the Business Model dimension

		Dimension "B-D1, P-S Business Model"				
		Question 1	**Question 2**	**Question 3**	**Question 4**	**Question 5**
Use-Case	**1**	Moderately studied	Joint	Symbiotic	To provide IT tools and platforms	Virtual design tools
	2	Moderately studied	Separation	Bundling	To increase knowledge about this dimension, To provide IT tools and platforms	n.a.
	3	Lowly studied	Bundling	Joint	To increase knowledge about this dimension, To provide structured methods	n.a.
	4	Highly studied	Separation	Bundling	To increase knowledge about this dimension, To provide structured methods	Business Model and Risk Analysis methods

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[1] The complete version of the questionnaire is accessible here: https://goo.gl/forms/JAgqaHkRwq8Tg1wH2.

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