PSS Modularization: A Customer Driven Integrated Approach

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PSS MODULARIZATION: A CUSTOMER DRIVEN INTEGRATED APPROACH

Abstract

The shift from product ownership to integrated solutions (Product-Service Systems (PSSs)) is expected to lead to a higher customer satisfaction in many cases compared to providing products and services separately. PSS providers are required to add more value to the products they offer, as well as to augment and diversify the services related to these products. To deal with this complex task, the paper proposes a practical methodology to support manufacturers in designing services related to the proper functioning of their products fulfilling customers' needs and expectations. This approach is based on the synergic use of Quality Function Deployment for PSS (QFDforPSS), Axiomatic Design (AD), and the service blueprint tools, providing a correlation between the customers' expectations, the PSS components, and the PSS modules. The methodology was verified by means of a service modularization for PSS at a company operating in the biomedical sector. While the proposed approach needs to be validated through further studies in different contexts, its positive results in reducing both the risk of overdesigning and the possibility of creating design conflicts can contribute practically to the scientific knowledge on the development of integrated solutions.

Keywords: Product-Service System; customer satisfaction; Quality Function Deployment; Axiomatic Design; modularization

1. Introduction

Product-Service Systems (PSSs) represent one of the most suitable solutions for companies to deal with nowadays market needs, and numerous studies focus on their implementation to enhance companies' performances, as well as customer satisfaction and environmental concerns (Baines et al. 2007; Meier, Roy, and Seliger 2010; Sakao and Fargnoli 2010; Durugbo 2013; Vasantha et al. 2012; Vezzoli et al. 2015; Fargnoli et al., 2018). A PSS is based on providing the customers with integrated solutions based on functional results instead of traditional product sales (Haber and Fargnoli 2017a). While the request for integrated offerings is increasing (Hakanen, Helander, and Valkokari

2016), most of product providers started thinking on how to develop services related to their products' functioning after the product is ready for realization (Matschewsky, Kambanou, and Sakao 2017). Thus, focusing on the development of service-oriented products, it is fundamental to provide solutions that satisfy both customers and companies' needs (Gao et al. 2011; Kimita, Shimomura, and Arai 2009). This task is complex because it needs to ensure the design quality of both products and services based on customers' requirements (Mourtzis et al. 2017). It also needs to avoid the risk of overdesigning and properly balance products and services (Sakao and Shimomura 2007; Suh and Jeon 2016). Addressing products and services simultaneously implies a higher possibility of creating conflicts to be solved in design rather than addressing products or services separately (Song and Sakao 2017). Despite the evident challenge originating from the higher complexity, little insight is available in the literature to deal with it. Therefore, the reduction of the complexity in PSS design needs to be further investigated. To solve these complexity problems, PSS providers should adopt a holistic approach that allows them to understand the customers' needs and wants effectively, and to manage the whole life cycle of the provided solution, making the possibility of changing or updating the PSS components easier. Several studies have addressed these issues (i.e. Song et al. 2015; Sakao, Song, and Matschewsky 2017). However, these earlier studies do not address market demands to minimize the risk of customer dissatisfaction. In such a context, the present study aims at proposing a possible solution by answering the following research questions:

RQ1. How can the complexity of addressing requirements in PSS design be reduced while maintaining the PSS's potential of satisfying market demand?

RQ2. How can service modules of a PSS be created based on customer values?

To answer the above questions, the paper presents a methodology based on the synergic use of Quality Function Deployment for PSS (QFDforPSS) (Arai and Shimomura 2005), the Axiomatic Design (AD) method (Suh 1998), and the service blueprint (Hara, Arai and Shimomura 2009). Gilbert, Lindsey, and Omar (2014) integrated QFD and AD to reduce the intricacies of customer requirements at a conceptual level. This allows a reduced number of iterations while using QFD which improves its effectiveness and reduces costs for the provider (Goncalves, Mourão, and Pereira 2005). Whereas, the service blueprint allows a representation of the PSS characteristics to identify and elucidate the relationships among the stakeholders and the PSS elements (Fließ and Kleinaltenkamp 2004), providing a key starting point for the PSS design process (Geum and Park 2011).

The remainder of the paper is articulated as follows: the next section discusses the research background and motivations. In Section 3, the research approach is depicted, while in Section 4 its validation through a practical case study concerning the PSS implementation in the biomedical context is described. Hence, Section 5 discusses the results achieved, and Section 6 concludes the paper addressing further research work.

2. Research Background and Motivations

The shift from product ownership to function-oriented products is expected to lead to a higher increase of customer satisfaction in many cases compared to the provision of Separated Products and Services (SPS), as noted by Suh and Jeon (2016), who remarked the importance of the degree of transformation from product to service, suggesting that PSS developers need to pay attention to the proper balancing between them. Gebauer and Kowalkowski (2012) stressed on the companies' need to increase their capability in implementing a service network. This means that PSS providers are required to add more value to the products they offer, as well as to augment and, if necessary, diversify the services around these products (Phumbua and Tjahjono 2011; Kimita and Shimomura 2014). Nevertheless, such an effort might lead to the risk of overdesigning, i.e. developing systems that exceed customers' needs and consequently to both an extra investment of resources (in terms of time, costs, human resources) and the generation of design conflicts (Coman and Ronen 2010; Smith, Smith, and Shen 2012; Belvedere, Grando, and Ronen 2013; Fargnoli, De Minicis and Tronci 2014). As noted by Song and Sakao (2017), solving design conflicts in a PSS context is more difficult than in a conventional product-reliant environment. In fact, once the customers' requirements are defined, a large effort is requested to effectively transform them into design requirements (Hakanen, Helander, and Valkokari 2016) and to address the PSS provider strategies considering the whole PSS life cycle, i.e. on a long-term perspective (Meier, Roy, and Seliger 2010).

Moreover, taking into account a PSS life-cycle, if the customers' requirements change, the provider might need to change or modify the existing offering quickly. This requires additional resources and more significant design efforts due to the interdependences among the PSS components as remarked by Sakao, Song, and Matschewsky (2017), who suggested the modularization of services as a means to reduce complexity in PSS customization. Several studies analyzed the application of modular design to PSSs and the benefits that can be achieved through it (Wang et al., 2011; Kimita and Shimomura 2012). Aurich, Fuchs, and Wagenknecht (2006) identified process modularization as a promising approach for the integration of product and service design processes, proposing a modular design framework for technical PSSs. Similarly, Li et al. (2017) stressed that defining a system designed as a series of modules for the physical product and the services, which is aimed at satisfying the customer needs, plays a key role in solving conflicts between offering customization and the PSS providers' bottom line. Regarding this aspect, the economic objectives for manufacturers are strictly related to how efficiently the services are provided rather than the number of sold products (Fargnoli, De Minicis, and Tronci 2012). Qu et al. (2016) argued that, although numerous studies focus on design methodologies for PSS development, more attention should be directed to improve modularity by means of empirical research works.

At a more detailed level Song et al. (2015) discussed the adoption of extended graphical tools (e.g. service blueprint and fuzzy graphs) to identify service components and partition modules in the context of Product-Extension Services (PES). Their development is still an unexplored subject. Instead, Sakao, Song, and Matschewsky (2017) focused on the need to generate service modules for customizing PSSs, extending the use of the Design Structure Matrix (DSM) method (Eppinger and Browning 2012) to the domain of service modularization in order to define and cluster service components. The generation of modules of PSS components was also addressed by Kimita et al. (2010), who applied the Axiomatic Design (AD) method (Suh 1998) to achieve such a goal. On the one hand, this tool resulted in being very effective for the definition of the PSS features (i.e. service activities and product behaviours, as well as attributes of entities and modules). In fact, AD allows an efficient and systematic manner of defining and decomposing the system's requirements for the comprehensive fulfilment of the design objectives (Arcidiacono, Matt, and Rauch 2017). It relies on the Independence and Information Axioms to make use of the least amount of information for a robust design that meets all of the functional requirements (Harutunian et al., 1996; Suh 2001; Kandjani et al. 2015). On the other hand, Kimita et al. (2010) also underlined the difficulties in the definition of the information to be used as input, which should be carefully prepared to avoid design conflicts, e.g. uncoupled modules. In other words, the reduction of the complexity to augment customer satisfaction requires to be further investigated, and a proper methodology to address such an issue is needed. Song and Sakao (2017) underlined the lack of a systematic and comprehensive support for PSS customization, and addressed a module-based configuration as a key-approach to enhance the PSS customization since the early design stages. Merging all these research clues, we focused our attention on how to identify service components and modules when developing a PSS in a practical context, with the goal of highlighting the relationship between service components and modules from one side, and customer satisfaction from the other.

3. Research Methodology

Relying on the above considerations, we focused our attention on three main objectives PSS providers should pursue when developing a PSS:

(1) Mapping the whole PSS life-cycle, taking into account all of the stakeholders involved;

(2) Identifying customers' needs and wants properly, as to implement PSS characteristics and components that augment their perceived value; and

(3) Identifying service components and service modules, as well as their relationships with customers' requirements.

3.1 PSS Lifecycle Mapping

PSS providers need to visualize the actual and expected integration of products and services, as well as its progression through the PSS life cycle, taking into account both the developer and the customers' perspectives. To achieve such a goal, the service blueprint is widely used to effectively map the whole PSS life-cycle considering all stakeholders involved (Park, Geum, and Lee 2012; Barquet et al. 2013; Reim, Parida, and Örtqvist 2015). Such a tool fits with the features of both the flow and scenario models (Sakao et al. 2009) and allows engineers to combine activities and functions to address solutions at different stages of the PSS development (Song et al. 2015; Kim et al. 2016). Accordingly, we propose an Adapted Service Blueprint (ASB) based on the service blueprint suggested by Hara, Arai and Shimomura (2009). The proposed ASB extends the traditional service blueprint by denoting the "visible" and "invisible" activities of each PSS provider as the customer may interact with several providers (i.e. retailer, distributor, manufacturer). This adaptation hence provides a clearer visualization of the stakeholder interactions.

3.2 Definition of Customer Requirements

An abundance of studies recognizes the Quality Function Deployment (QFD) method (Akao 1990) as one of the most powerful means to identify and assess customers' expectations, translating them into technical characteristics of a product, a service or a combination of them. Accordingly, numerous QFD extensions and augmentations have been proposed covering a broad range of fields (Carnevalli and Miguel 2008; Fargnoli and Sakao 2017). In the PSS context, the Quality Function Deployment for PSS (QFDforPSS) has been introduced (Arai and Shimomura 2005; Sakao and Shimomura 2007) by extending the traditional QFD in a two-phase tool where:

- The service aspects are addressed similarly to the product's, considering them at the same time in the "hows" of QFD, i.e. product and service characteristics in Phases I as well as product and service components in Phase II (Figure 1). It has to be noted that, in accordance with the traditional QFD method (Akao 1990), in this study the assessment of the relationships between the elements of the two relationship matrices is carried out by means of a 1-3-9 scale (where 1 designates a weak relationship, 3 a medium one and 9 a strong one).

- The Voice of the Customer (VoC) in QFD is replaced by the Receiver State Parameters (RSPs), i.e. any aspect that can represent a positive or a negative effect on a PSS receiver (Sakao et al. 2009). Therefore, adopting RSPs instead of VoC (i.e. customer requirements) improves the comparability between multiple RSPs: this contributes to maintaining the coherency and alignment of the "whats" in the QFD (Fargnoli and Sakao 2017).

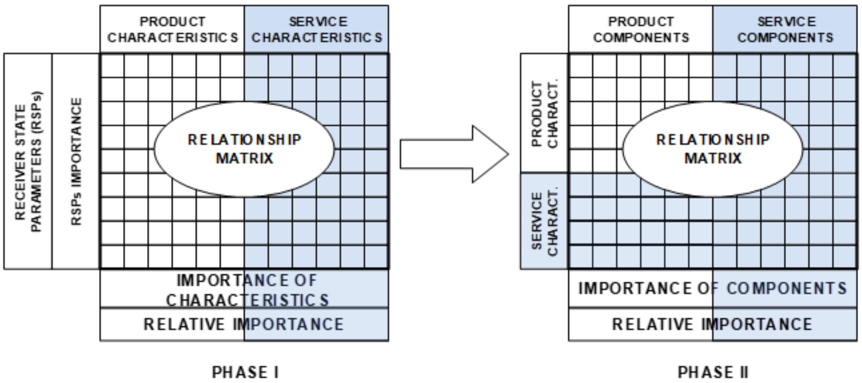


Figure 1. Scheme of the two phases of the 'QFDforPSS' method.

QFD is a customer-driven approach to develop products that utilizes relationships between market demand and solution characteristics to maximize customer satisfaction (Jeong and Oh 1998; Yeh, Huang, and Yu 2011). As the traditional QFD aims to ensure these results in product development, QFDforPSS can help to achieve these benefits in a PSS context properly (Fargnoli and Sakao 2017), reducing the risk of customer dissatisfaction.

3.3 PSS Modularization

As discussed in the previous section, the definition of service modules satisfying the customer needs plays a key role in PSS development and supports engineers in avoiding possible conflicts among the various PSS components. Although its use in the PSS context is scarcely documented (Kimita et al. 2010; Hosono et al. 2011), we believe that the use of the Axiomatic Design (AD) method can be very beneficial to provide an effective analysis of the PSS functional requirements, providing independent modules of PSS components. The main reasons of this assumption rely on this tool's recognized properties, allowing engineers to create synthesized solutions in the form of products, processes or systems that satisfy perceived needs through mapping and clustering Functional Requirements (FRs), Design Parameters (DPs) and Process Variables (PVs) as schematized in Figure 2. More in details, the FRs represent the functions related to the Receiver State Parameters (RSPs), the DPs represent the service activities and the PVs are the attributes of entities. The final goal of the application consists in the definition of the design matrix [C], which can be obtained as a product of the matrix [A] per the matrix [B], consisting of the following:

$$[A] = \{FRs\} / \{DPs\} \text{ and } [B] = \{DPs\} / \{PVs\} \quad (1)$$

where {FRs}, {DPs}, and {PVs} are the vectors representing functions, service activities, and attributes respectively.

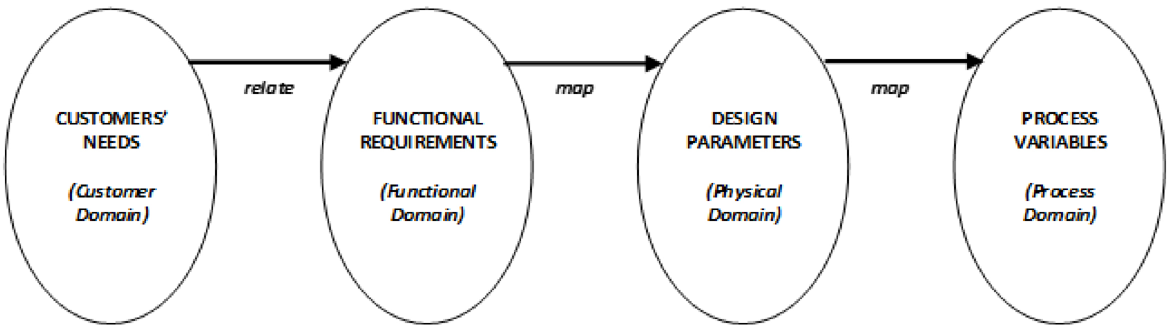


Figure 2. General scheme of the AD approach.

Moreover, the AD integration with the QFD method augments the effectiveness of the latter, providing independent solutions (Kulak, Cebi, and Kahraman 2010; Du et al. 2013). This can reduce the occurrence of design conflicts (Pimapunsri and Tichkiewitch 2013), which in this study are regarded from the independence standpoint.

Hence, the use of AD in PSS modularization enables a rational module creation, where a PSS Module represents a minimum subset of module components that are independent of the others (Kimita et al. 2010). To make it clearer, in this study the PSS modularization is based on the definition of Service Modules (SMs), where a SM is defined as a minimum subset of Module Components (MCs) that are independent of the other MCs, in line with Suh and Do (2000).

3.4 General Framework

The proper integration of these tools in a framework that guides engineers in the development of a PSS is needed to combine and augment their effectiveness, especially when considering the operative needs of PSS providers. With this aim in mind, an integrated methodology was developed as shown in Figure 3.

More in details, the proposed methodology consists in the following three main phases:

(1) PSS Components definition. The input of this phase is represented by the analysis of the current situation concerning the market (i.e. the business model adopted by the company) and the analysis of the customer requirements. The output consists in the definition of the PSS Characteristics and Components thanks to the use of the QFDforPSS method. Specifically, the service components were defined according to their related resources: human, information, and service tools (Sakao, Song, and Matschewsky 2017).

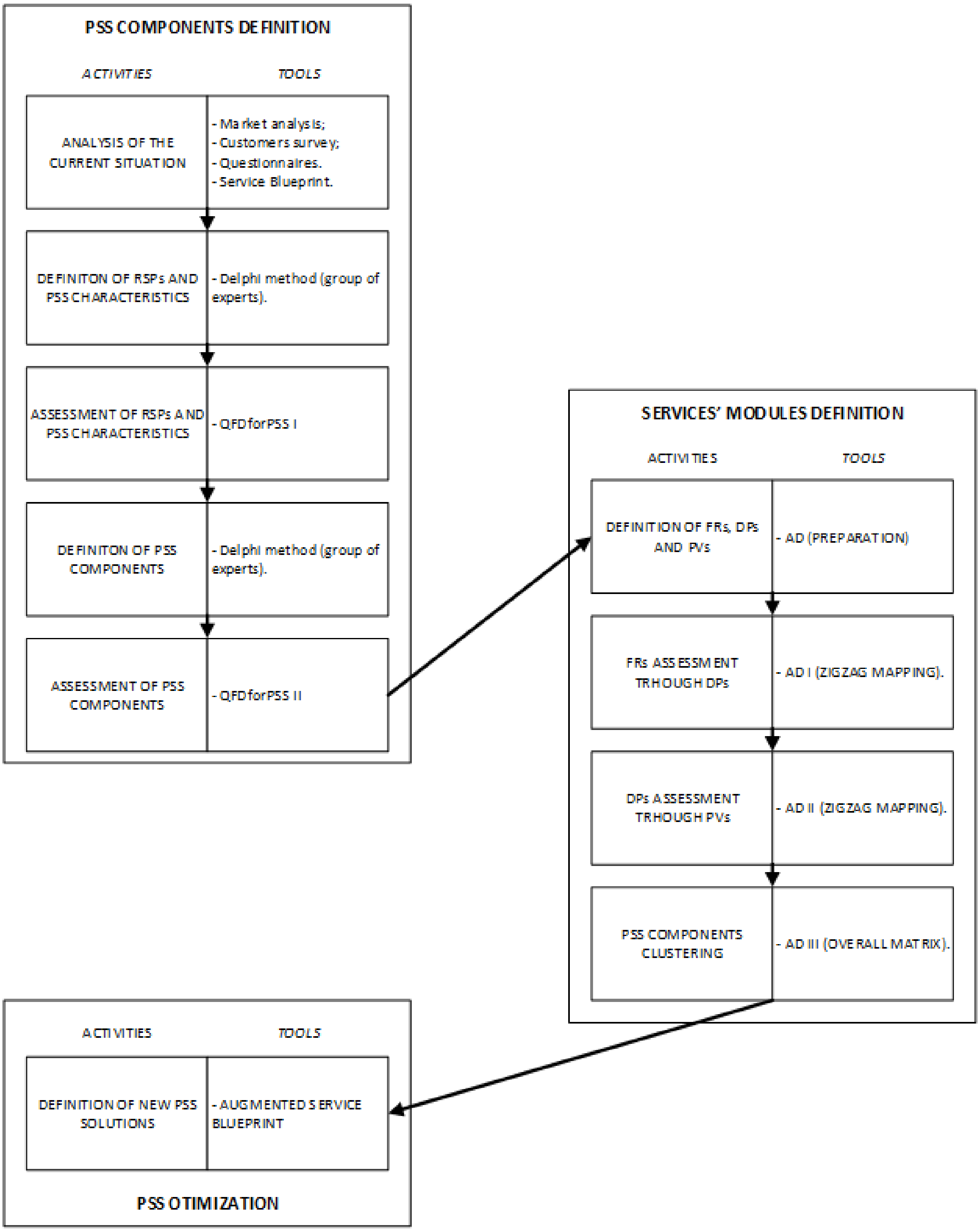


Figure 3. Scheme of the proposed methodology.

(2) Services' Modules definition. The second step is based on the application of the AD method. In doing so, we only consider as input for the AD the Service Components (SCos) because of two main reasons: they resulted in being more

relevant than the Product Components (PCos), as per the customer satisfaction analysis; the company can operate modifications on services more easily than on physical components, as per the company experts' advice. Thus, Functional Requirements (FRs), Design Parameters (DPs), and Process Variables (PVs) are derived from the analysis of the SCos obtained by means of the QFDforPSS method: i.e. while the definition of PVs is directly based on information concerning the SCos, engineers can define FRs and DPs through a bottom-up reasoning that starts from the SCos and uses the gathered knowledge concerning RSPs and SChs. In other words, SCos are used to individuate general FRs which are then decomposed into sub-functional requirements to define DPs and PVs. Accordingly, through the AD application, a set of independent Service Modules (SMs) is defined, given that each of one them is determined by one or more Module Components (MCs) in accordance with Suh and Do (2000). Hence, while SCos provide general information concerning the services that affect RSPs, MCs represent their functional decomposition and characterization. Thereby, on the one hand, a SCo can be related to (or influenced by) other SCos. On the other hand, the change in a specific SM, which is derived by a proper combination of one or more MCs, only influences the corresponding functions and characteristics of that SM without affecting other SMs.

(3) PSS optimization. The definition of the service modules leads to a new (modified) PSS and hence a modified solution. The augmented service blueprint enables visualizing the interactions that take place between the PSS modules and the stakeholders.

4. Case Study

The proposed methodology was verified through its application to a practical case study in collaboration with a company that provides biomedical devices. The main customers and hence users of the devices are public hospitals and centres, by means of public procurement rules (i.e. a regulated market), while 30% of the company's customers are represented by private clinics. In detail, the company distributes medical imagery equipment used mainly for echography but also for therapy and research purposes. To better understand the context, interviews with company experts were held in order to define the involved actors and their activities from one hand as well as their requirements on the other. In particular, market surveys gathered by the marketing team concerned the maintenance process as customer data revealed dissatisfaction concerning the actual maintenance service. In addition, since the company operates in a regulated market operated by public bodies, 10 calls for tender in a 24-months period (2015-2016) were selected and analysed to obtain a clearer and more thorough understanding of the customers' requirements concerning the supply of the equipment and the related services requested. This allowed us to map the processes involved in the PSS supply by means of the ASB method.

4.1 PSS Components Definition

This activity included the analysis of both the tangible and the intangible characteristics required by the calls, as well as the criteria used to assess the offerings. The result of these analyses was the definition of the Customer Requirements (CRs), which were transformed into Receiver State Parameters (RSPs) with the aim of applying the QFD for PSS method (Table 1). Furthermore, 10 selected customers (i.e. medical professionals who operate the equipment on a daily basis) were asked to evaluate the importance of each CR/RSP on a 1-to-5 scale (where 1 designates the lowest level of importance and 5 the highest).

Table 1. List of the CRs and RSPs.

CUSTOMER REQUIREMENTS		RECEIVER STATE PARAMETERS	
CR1	Easy to use	RSP1	Easiness to use
CR2	Easy to maintain	RSP2	Availability of the equipment
CR3	Technical capability	RSP3	Technical performances
CR4	Versatile equipment	RSP4	Functionality
CR5	Upgradable system	RSP5	Upgradability
CR6	Safe and reliable functioning conditions	RSP6	Operability
CR7	Provision of data storage	RSP7	Data storage availability
CR8	Provision of consumables	RSP8	Inclusion of consumables
CR9	Provision of technical support	RSP9	Availability of technical support
CR10	Capability of technical support	RSP10	Quality of technical support

Similarly, the Product Characteristics (PChs) and Service Characteristics (SChs) were defined (Table 2). Due to a non-disclosure agreement, here and after some information was simplified to protect the company's confidential and proprietary information and data.

Table 2. List of the PChs and SChs.

PRODUCT CHARACTERISTICS		SERVICE CHARACTERISTICS	
PCh1	Quality of product manual	SCh1	Provision of online support for additional information
PCh2	Ergonomics (user-friendly interface operator-machine)	SCh2	Provision of online training courses for users
PCh3	Number of setup operations	SCh3	Time for response
PCh4	Operational availability (in terms of MTBF(Mean Time Before Failure) and MTTR (Mean Time To Repair))	SCh4	Time for recovery
PCh5	Imaging quality	SCh5	Time for replacement
PCh6	Data storage capability	SCh6	Provision of software upgrades
PCh7	System effectiveness (e.g. power of Central Processing Unit (CPU))	SCh7	Provision of additional user training in case of available updates
PCh8	Multi-functionality of devices	SCh8	Compliance with maintenance schedule
PCh9	Software modularity	SCh9	Provision of a cloud platform for data storage and transmission
		SCh10	Provision of sufficient consumables
		SCh11	Quality of customer care service
		SCh12	Assistance to environmental and safety compliance
		SCh13	Provision of periodic training of customer care personnel
		SCh14	Provision of periodic training of maintenance service staff

Based on this information, the first phase of the QFD for PSS was carried out (Table 3) and the relationships between the RSPs and the PChs and SChs were defined.

Table 3. QFDforPSS Phase I.

		Product Characteristics									Service Characteristics													
	RSP Importance	PCh1	PCh2	PCh3	PCh4	PCh5	PCh6	PCh7	PCh8	PCh9	SCh1	SCh2	SCh3	SCh4	SCh5	SCh6	SCh7	SCh8	SCh9	SCh10	SCh11	SCh12	SCh13	SCh14
RSP1	4	3	3	3			1		1	1	3	3				1	3		1			3		
RSP2	5				9		1			3	1	1	3	3	3	1	3	9	1	3		1		3
RSP3	4					3	3	9	3							3		1	3					
RSP4	2		3	1					9	3									1					
RSP5	3			1	3		1			3						9	3		1					
RSP6	4				3						1					1		9		1		3		
RSP7	3						3												9					
RSP8	3			1					1											9				
RSP9	5										3	3	9				3				9	9		
RSP10	5												3	9	9			3					9	9
	Ch Absolute Importance	12	18	20	66	12	33	36	37	34	36	32	75	60	60	52	51	10 0	53	46	45	74	45	60
	Ch Relative Importance	1%	2%	2%	6%	1%	3%	3%	4%	3%	3%	3%	7%	6%	6%	5%	5%	9%	5%	4%	4%	7%	4%	6%

The resulting HoQ was then analysed to identify the PSS components that can suit the obtained characteristics. To do so, the components of the PSS solution (i.e. product and service) were defined (Table 4). Hence, following the same criteria of Phase I, in the second phase of the QFD for PSS the Product Components (PCos) and Service Components (SCos) were assessed and their resulting importance was deduced (Table 5).

Table 4. List of the PCos and SCos.

PRODUCT COMPONENTS		**SERVICE COMPONENTS**	
PCo1	Touch screen monitor	SCo1	Users periodic training programmes (information)
PCo2	Chariot system with swivel wheels	SCo2	Decentralized service centres (service tools)
PCo3	Apple-probe grip: the shape and the grip of the probes should be as comfortable as possible	SCo3	Maintenance service centers (service tools)
PCo4	An ergonomic keyboard (i.e. v-shaped)	SCo4	Wide range of probes (service tools)
PCo5	Quick start facilitating safe access and configuration of the system	SCo5	Wizards to update software (service tools)
PCo6	Robust transducers	SCo6	Wearable parts: coupling rubbers, filters, etc. (service tools)
PCo7	Full HD display	SCo7	Remote monitoring system of machine parameters (service tools)
PCo8	Hard disk with large storage space	SCo8	Database of patient analysis (information)
PCo9	Powerful CPU	SCo9	Calendar of ultrasound gel delivery (information)
PCo10	Number of probes connectable simultaneously to the system	SCo10	Larger number of customer care personnel (human)
PCo11	Customizable pre-sets	SCo11	Environmental and safety compliance assessment data (information)
PCo12	Spare battery: in case of blackouts, in order not to lose data	SCo12	Periodically trained customer care personnel (human)
		SCo13	Periodically trained maintenance technicians (human)
		SCo14	Periodically trained third party technicians (human)
		SCo15	Qualified training instructors (human)

Table 5. QFDforPSS Phase II.

				Product Components												Service Components														
		Ch Importance	Ch Relative Importance	PCo1	PCo2	PCo3	PCo4	PCo5	PCo6	PCo7	PCo8	PCo9	PCo10	PCo11	PCo12	SCo1	SCo2	SCo3	SCo4	SCo5	SCo6	SCo7	SCo8	SCo9	SCo10	SCo11	SCo12	SCo13	SCo14	SCo15
Product Characteristics	PCh1	12	1%	3												9				1							3			
	PCh2	18	2%	3	3	9	9	3																						
	PCh3	20	2%	1				9		1				3																
	PCh4	66	6%										3		3	9	3	3	3		3	3		3			1	9	9	3
	PCh5	12	1%						9	9		1																		
	PCh6	33	3%								9												3							
	PCh7	36	3%	1				1				9	1	1						1	1	1								
	PCh8	37	4%						1				9						9											
	PCh9	34	3%						1				1							9										
Service Characteristics	SCh1	36	3%													1											9			
	SCh2	32	3%													9														
	SCh3	75	7%								1						9	9						3	3		1	3	3	
	SCh4	60	6%																									9	9	3
	SCh5	60	6%														9	3										1	1	
	SCh6	52	5%													3				9										
	SCh7	51	5%													1				3										
	SCh8	100	9%												3		3	1						3				1	1	1
	SCh9	53	5%								3											9	9							
	SCh10	46	4%						1						1				9		9			9						
	SCh11	45	4%													1								1	9		3			
	SCh12	74	7%																							9				
	SCh13	45	4%																						1		9			3
	SCh14	60	6%																									9	9	3
	Co Absolute Importance			146	54	162	162	270	225	128	531	336	601	96	544	1278	1713	1153	945	975	648	711	576	1182	675	666	1041	2059	2059	793
	Co Relative Importance			1%	0%	1%	1%	1%	1%	1%	3%	2%	3%	0%	3%	6%	9%	6%	5%	5%	3%	4%	3%	6%	3%	3%	5%	10%	10%	4%

4.2 Service Modules (SMs) Definition

The further step consisted in the definition of the SMs to properly address the PSS implementation. With this goal in mind, the AD method was applied in collaboration with the company's experts. Based on the information collected and obtained by means of the QFDforPSS, the Functional Requirements (FRs), Design Parameters (DPs), and Process Variables (PVs) were defined, as mentioned in Section 3. Based on this, and to achieve a higher level of detail and hence a more feasible design, FRs, DPs, and PVs were obtained starting from the analysis of SCos, as summarized in Table 6.

Table 6. Scheme of the application of the AD method.

Activity	Input	Output
Translation of SCos into functional form	SCos, SChs, RSPs	Functional Requirements (FRs)
Mapping from FRs to DPs (AD zigzag mapping)	FRs	Design Parameters (DPs) {FRs} = [A] {DPs}
Mapping from DPs to PVs (AD zigzag mapping)	{FRs} = [A] {DPs}	Process Variables (PVs) {DPs} = [B] {PVs}
Mapping from FRs to PVs to obtain the overall matrix [C]	{FRs} = [A] {DPs} {DPs} = [B] {PVs}	{FRs} = [C] {PVs} [C] = [A] x [B] Modules and Modules' Components (MComps)

An excerpt of this analysis' results is shown in Table 7, while the final design matrix (overall matrix) that describes the relationships between the functions {FRs} and the attributes {PVs} is represented in Table 8, where an X indicates a value different from zero, and thus a dependence between an FR and a PV.

Table 7. Elementary decomposition of the FRs, DPs and PVs (excerpt).

FUNCTIONAL REQUIREMENTS		DESIGN PARAMETERS		PROCESS VARIABLES	
FR1	Plan users training	DP1	Course planning for users	PV1	Capability of course planning for users
FR1.1	Schedule resources for users training	DP1.1	Resource allocation for users' courses	PV1.1	Resource efficiency for users' courses
FR2	Guarantee full territorial coverage of the service centres	DP2	Distribution of the service centres	PV2	Optimal service centres distance
FR2.1	Ensure the right number of decentralized service centres	DP2.1	Allocation of service centres	PV2.1	Effectiveness of service centres allocation
FR2.2	Ensure the right location of decentralized service centres	DP2.2	Placement of service centres	PV2.2	Effectiveness of service centres placement
FR3	Provide an appropriate number of maintenance service technicians	DP3	Recruitment of a proper number of maintenance service technicians	PV3	Capability of selecting a proper number of maintenance service technicians
FR3.1	Organize scheduling of maintenance service technicians	DP3.1	Management of the selected number of maintenance service technicians	PV3.1	Effectiveness of the selected number of maintenance service technicians
FR4	Supply a wide range of probes	DP4	Management of probes functionality	PV4	Compatibility of probes
FR4.1	Supply a range of probes for each type of analysis	DP4.1	Management of probes for each type of analysis	PV4.1	Compatibility of probes for each type of analysis
FR4.2	Supply a range of probes for each type of patient	DP4.2	Management of probes for each type of patient	PV4.2	Compatibility of probes for each type of patient
FR5	Ensure wizards for upgrading software	DP5	Development of wizards for upgrading software	PV5	Usability of wizards for upgrading software
FR5.1	Ensure personnel to develop wizards	DP5.1	Development interface of wizards	PV5.1	User-friendliness of wizards' interface
FR6	Provide extra wearable parts	DP6	Delivery of wearable parts	PV6	Frequency of wearable parts deliveries
FR6.1	Guarantee availability in stock of extra wearable parts	DP6.1	Amount of wearable parts to deliver	PV6.1	Promptness of wearable parts deliveries
FR7	Allow remote control of machine parameters	DP7	Real-time machine status control	PV7	Real-time malfunction warnings
FR7.1	Ensure monitoring of machine status	DP7.1	Machine data transmission	PV7.1	Instant alarm warnings feature for machine breakdown
…	……………………………………	…	……………………………………	…	……………………………………
FR15.1	Perform verifications on training instructors	DP15.1	Ranking list of training instructors	PV15.1	Correctness of ranking list of training instructors
FR15.2	Monitor conduct of training instructors	DP15.2	Follow-up of training instructors	PV15.2	Accuracy of monitoring of training instructors

Table 8. The design matrix between the elementary {FRs} and {PVs}.

	$PV_{1.1}$	$PV_{2.1}$	$PV_{2.2}$	$PV_{3.1}$	$PV_{4.1}$	$PV_{4.2}$	$PV_{5.1}$	$PV_{6.1}$	$PV_{7.1}$	$PV_{8.1}$	$PV_{8.2}$	$PV_{9.1}$	$PV_{10.1}$	$PV_{11.1}$	$PV_{11.2}$	$PV_{12.1}$	$PV_{13.1}$	$PV_{14.1}$	$PV_{15.1}$	$PV_{15.2}$	**Modules Components**	**Service Modules**
$FR_{1.1}$	X																				$MC_{1.1}$	**SM_1** : Unit for users training
$FR_{2.1}$		X	X					X				X						X			$MC_{2.1}$	**SM_2** : Unit for service centers management
$FR_{2.2}$			X					X				X									$MC_{2.2}$	
$FR_{3.1}$				X																	$MC_{3.1}$	**SM_3** : Unit maintenance operators management
$FR_{4.1}$					X			X													$MC_{4.1}$	**SM_4** : Unit for spare parts management
$FR_{4.2}$						X		X													$MC_{4.2}$	
$FR_{5.1}$							X														$MC_{5.1}$	**SM_5** : Unit for software engineering
$FR_{6.1}$								X													$MC_{6.1}$	**SM_6** : Unit for wearing parts management
$FR_{7.1}$									X		X										$MC_{7.1}$	**SM_7** : Unit for Cloud computing provision
$FR_{8.1}$										X	X										$MC_{8.1}$	
$FR_{8.2}$											X										$MC_{8.2}$	
$FR_{9.1}$												X									$MC_{9.1}$	**SM_8** : Unit for consumables management
$FR_{10.1}$													X								$MC_{10.1}$	**SM_9** : Unit for customer care management
$FR_{11.1}$														X	X						$MC_{11.1}$	**SM_{10}** : Unit for environmental and safety assistance
$FR_{11.2}$															X						$MC_{11.2}$	
$FR_{12.1}$																X					$MC_{12.1}$	**SM_{11}** : Unit for customer care training
$FR_{13.1}$																	X		X		$MC_{13.1}$	**SM_{12}** : Unit for maintenance technicians training
$FR_{14.1}$																		X	X		$MC_{14.1}$	
$FR_{15.1}$																			X	X	$MC_{15.1}$	
$FR_{15.2}$																				X	$MC_{15.2}$	

More in detail, regarding the independence of the SMs, when a MC is uncoupled, it defines a single Service Module. For example, SM_1 (Unit for users' training) is defined by $MC_{1.1}$ by means of the following equation:

$$\{FR_{1.1}\}. = [X]\ \{PV_{1.1}\} \qquad (2)$$

Conversely, when MCs are decoupled, to satisfy the Independence Axiom a proper design sequence was adopted to determine a Service Module. For example, the service module SM_{10} (Unit for environmental and safety assistance) is determined by the Module Components $MC_{11.1}$ and $MC_{11.2}$ in accordance with the sequence derived by the following equation:

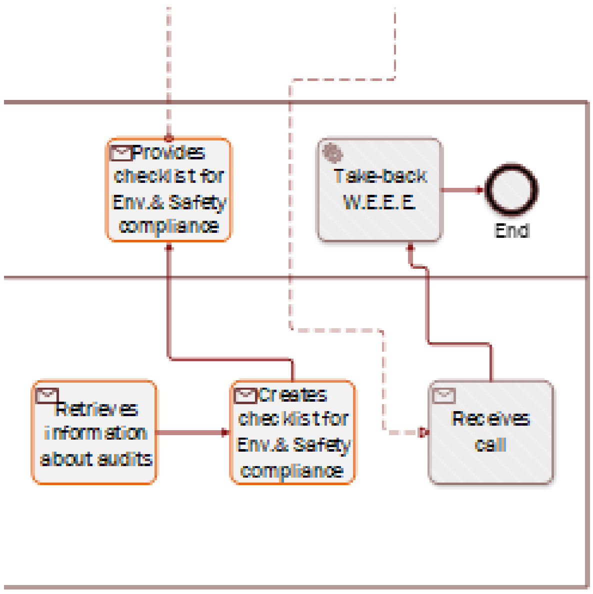
$$\begin{Bmatrix} FR_{11.1} \\ FR_{11.2} \end{Bmatrix} = \begin{bmatrix} X & X \\ 0 & X \end{bmatrix} \begin{bmatrix} PV_{11.1} \\ PV_{11.2} \end{bmatrix} \qquad (3)$$

The results obtained allowed us to define the Module Components (MCs), grouped in 12 independent Modules (Table 8).

The independence of SMs allowed us to eliminate design conflicts. This is in line with research clues of Kimita et al. (2010), who underlined that when the independence among the SMs is provided, an intervention on a particular module has no influence on the others, and consequently it can be operated while avoiding conflicts with the other modules.

Accordingly, the map of the processes related with the PSS was modified taking into account all the actors involved: the provider, the receiver, the customer care centre, the external maintenance operators (i.e. third parties), and the cloud computing provider for data exchange and storage. Where the last one is a new actor introduced to fulfil the customers' requirements, that is to have the opportunity to remotely control and to check the machinery parameters in the medium-to-long term, and to have more storage space for the diagnosis data, in addition to the fitted hard-disk. For these reasons, a new service has been implemented (Service Module SM7), designing the product-service based on the effective customers' expectations: the cloud service enables remote monitoring of the machine status and the remote storage of the patients' data. Another relevant modification concerns the implementation of an additional service consisting in providing technical support in managing environmental, and health and safety issues (Service Module SM10), which are quite relevant in hospitals and clinics due to compulsory requirements and the frequent need to adopt quality management systems. In Figure 4 an excerpt of the modified service blueprint related to this new service is represented. Furthermore, to satisfy the customers' needs concerning the upgradability of the software, the development of specific "wizards" is foreseen (Service Module SM5): this allows easier software updates, which can be carried out directly by the customer.

Figure 4. Excerpt of the ASB method.



5. Discussion of results

5.1. Comparison with related works in scientific literature

From a methodical perspective, the use of AD in synergy with QFD is not a novelty, as pointed out by several authors (e.g. in (Goncalves, Mourão, and Pereira 2005; Carnevalli, Miguel, and Calarge 2010; Sun et al. 2010)). In this ambit, two main approaches can be found:

(1) The use of AD to augment the House of Quality, as discussed for example by Ashtiany and Alipour (2016);

(2) The use of QFD results as input for the AD application (e.g. in (He, Tang, and Chang 2009; Shao et al. 2016)), where most of the applications are limited to the use of the HoQ only.

In this study, we followed the latter approach. We used the QFDforPSS method to capture and organize information concerning the customers' needs and expectations, i.e. the market demand, in order to define the technical attributes (SChs and SCos) able to satisfy them. Hence, these data were further used to find a possible service design solution by means of the AD, which allowed us to individuate independent service modules whose combination can lead to an improved PSS solution.

With regard to the studies that focused on the PSS modularization mentioned in previous sections, the proposed approach represents an augmentation of the one by Kimita et al. (2010). On the one hand, while in the latter a structured procedure for gathering information to use as input for the AD application is not provided, in our approach the use of the QFDforPSS for this purpose is suggested. In this way, a more transparent and replicable approach is provided, and the quality of data is augmented since engineers can use not only RSPs but also SChs and SCos to define FRs, DPs and PVs. On the other hand, to identify the RSPs, Kimita et al. (2010) proposed a stakeholders' perspective that allows the stakeholders involved in the PSS to prepare the assigned PSS components concurrently. Differently, our study is more focused on the company's perspective (the PSS provider), which could rely on third-party companies (e.g. a company for maintenance interventions at the customers' sites) in the context of its PSS supply. In the present study, the expectations of the receivers of the PSS offering (e.g. hospitals and clinics) were taken into account while the needs of other stakeholders (e.g. service suppliers) can be addressed when the implementation of the service modules is concerned.

Similarly, also the approach proposed by Sakao, Song, and Matschewsky (2017) is based on a different standpoint since their modularization approach uses the resources needed for the fulfilment of the services from the provider's standpoint. Hence, this allows greater flexibility and easier customization, especially in the case of companies operating on a large scale. On the contrary, the approach proposed in the present study derives from the customers themselves. In other words, the service modules can be seen as customer-driven as opposed to provider-driven. Thus, our approach is more effective for a company that needs to modify the current PSS according to changing customer needs by focusing on the optimization of service activities. Hence, taking into account the latter aspect, the proposed methodology could be considered closer to the method proposed by Song et al. (2015), who addressed the modularization of product-extension services (PESs), related to the life cycle of a product. Moreover, they also focus on the importance of providing the manufacturer with an augmented blueprint to manage activities related to repair, maintenance, overhaul, and spare parts more efficiently. Despite these similarities, the present study differs from the one by Song et al. (2015) since it provides:

- A procedure to understand the customers' needs and expectations, with the goal of enhancing their satisfaction.
- A less complex methodology from the computational point of view, with the goal of making its usability larger.

In order to better clarify these considerations, in Table 9 a comparison between our approach and the above-mentioned approaches is provided, highlighting similarities and differences among them.

Table 9. Comparison between our approach and the other studies on PSS modularization.

Research study	General perspective	Input(s)	Modularization	Output(s)
Kimita, Akasaka, Hosono, and Shimomura (2010)	All stakeholders (providers and receivers)	QFDforPSS (RSPs)	Axiomatic Design	Stakeholder-driven solutions
Song, Wu, Li, and Xu (2015)	The provider (product-extension services)	Product-Extension Service Blueprint (PES Blueprint)	Product-Extension Service Blueprint (PES Blueprint) and correlation analysis	Provider driven solutions
Sakao, Song, and Matschewsky (2017)	The provider (novel services)	Interactions between service components	Design Structure Matrix	Provider-driven customized solutions
Song and Sakao (2017)	The provider (product-extension services)	HoQ, TRIZ, Service Blueprint	Fuzzy-graph based clustering	Provider-driven customized solutions
Present study	The provider (product-extension services)	QFDforPSS (RSPs, SChs and SCos); Adapted Service Blueprint (ASB)	Axiomatic Design	Customer-driven solutions

5.2. Practical benefits of the method

From a more practical point of view, the results showed that linking the functional decomposition with the service mapping, engineers can evaluate the influence of the service processes on the customers through the functions directly. This output answers RQ2 and represents one of the major findings of the proposed approach. Actually, the use of QFDforPSS in combination with both Axiomatic Design and the Service Blueprint methods augments their effectiveness in focusing on customer value, augmenting the research roadmap provided by Kimita et al. (2010) by providing a methodology aimed at enabling customization in PSS design. It has to be noted that differently from the approach proposed by Kimita et al. (2010), in our study we applied the AD method starting from the SCos. On one hand, this certainly requires additional effort since the complete QFDforPSS method has to be applied. On the other hand, such an approach allows us to better define FRs, since a bottom-up reasoning could be used thanks to the definition of RSPs and SChs, and their relationships with the SCos. It resulted helpful in reducing the risk of obtaining coupled results, and thus respecting the Independence Axiom of the AD method (Suh 1998). In other words, answering RQ1, such an approach can reduce the risk of overdesigning, while offering the PSS provider the potential of fulfilling the market demand. In addition, design complexity can be reduced as a functional approach (i.e. QFD and AD) and adequate mapping (ASB) clarify design perspectives by exposing the interactions between the stakeholders and the PSS elements, as well as the interactions among the stakeholders themselves. Moreover, the use of QFDforPSS renders a ranking of the PSS characteristics and components, supplying in this way engineers with useful information on customers' priorities. Such an understanding enables a clearer comprehension of the value perception by the customers and hence an improvement of the quality of the offered services. In addition, the Module Components (MCs) differ from the Service Components (SCos) derived from the QFDforPSS. In accordance with the above-mentioned definition, MCs represent a more detailed decomposition of the SCos, while a Service Module (SM) is represented by a set of MCs, in line with the approach proposed by Sakao, Song, and Matschewsky (2017). This aims at providing engineers with a more accurate solution to satisfy the customers' requirements.

It has to be noted that the customers' requirements can also include mandatory requirements, which might vary depending on specific contexts (e.g. legal requirements, requisites of voluntary standards, etc.). Hence, the application of the proposed procedure does not distinguish them based on their type (e.g. mandatory, voluntary, or expected requisites), but it can provide useful information on the attributes/characteristics that are necessary to satisfy them thanks to their functional decomposition and characterization. Thus, this also allows the company to decide whether to assign the implementation of a specific module concerning certain requisites to internal or external units (i.e. third-party suppliers) without affecting other service modules.

At the same time, we have to point out that the proposed approach enables the PSS provider to customize the offerings depending on the type of receiver. For example, based on the results of the present study, the company's experts decided to verify the opportunity to provide a system were the hard disk is replaced by a cloud service for data exchange and storage for private customers (the presence of a physical hard disk of a certain size is a requirement of the call for tenders in the case of public customers, hence it is mandatory). This demonstrates the benefits of the functional decomposition in PSS design, as well as the possibility of achieving more sustainable solutions when applying a PSS approach (Song and Sakao 2017). Similarly, it demonstrates in practice that a holistic approach can increase the differentiation levels of the offerings depending on customers' needs and without increased costs, in line with the findings of Sundin et al. (2009). Thus, this study can contribute in augmenting research knowledge aimed at providing a systematic and comprehensive support for a sustainable PSS modularization. In addition, potential benefits from the environmental point of view can be found thanks to the optimization of the services provided by the company. For example, the solution of providing specific wizards for assisting the customers was considered a very promising output of the study by the company's experts. They have estimated that this solution can reduce the number of interventions of the service operators by 50% in case of software updates. As demonstrated by Haber and Fargnoli (2017b), in a long-term perspective the reduction of maintenance interventions can be beneficial for the environment. Similarly, also the use of a cloud instead of a traditional hard disk can bring positive effects. For instance, the materials used and processed are minimized and the maintenance and disposal operations are reduced. Moreover, thanks to the definition of independent modules, the efforts needed by the provider in making a proposition that augments the fulfilment of the customer's needs and wants, ensuring the possible and feasible configuration of services, are reduced in line with research clues by Sakao, Song and Matschewsky (2017).

As far as the case study context is concerned, we have to note that on one hand it is often recognized as one of the sectors where the combination of tangible products and intangible services appears to offer greater possibilities for innovation and value creation due to its peculiarities (Mont 2002; Oliva and Kallenberg 2003). On the other hand, practical case studies in the servitization of the biomedical sector are lacking in the PSS literature (Mittermeyer, Njuguna, and Alcock 2011; Schröter and Lay 2014). Therefore, the present study contributes to the implementation of PSSs in this specific market, providing a methodology that allows medical equipment providers to design services related to the proper functioning of their goods hence fulfilling customers' needs and expectations. Thus, based on the above considerations, we believe that the practical contributions of this study in the PSS design research can be summarized as follows:

- The proposed procedure allows the definition of PSS configuration based on market demand by providing solutions tailored to the customers' needs while decreasing the risk of design conflicts.
- The integrated use of QFD for PSS with Axiomatic Design and Service Blueprint tools contributes in augmenting the knowledge in the PSS design context, thanks to the direct link created between the customers' needs and the PSS component modules.
- The results achieved provide additional evidence on the beneficial effects of PSSs regarding environmental sustainability, in line with prevalent studies in this field. Actually, although quantitative evidence has not been provided, the case study results highlight the potential benefits in terms of efficiency in providing service solutions that satisfy customers: i.e. the company can guarantee at least the same

level of customer satisfaction while reducing its efforts (e.g. the reduction of the number of maintenance interventions by the company's technicians, the reduction of hardware components replaced by software applications).

- The medical device sector is one of the most capable of benefiting from the application of the PSS approach and tools to enhance sustainability and customer value.

5.3 Limitations

Besides these positive aspects, we have to note that the present study also presents some limitations. Firstly, costs were not considered since the company mainly operates in a regulated market (public procurement mechanism by means of calls for tender). This market requires that manufacturers provide both the equipment and maintenance services for the duration of the contract, guaranteeing the respect of safety and environmental directives (Gelderman, Ghijsen, and Brugman 2006; Hatzopoulos and Stergiou 2011; Fargnoli et al. 2013). Consequently, since in such a context some services are normally provided, the implementation of a PSS approach appears less risky for companies operating in this sector than for other companies (Oliva and Kallenberg 2003). In addition, literature reports cases of providing PSS decreased life cycle costs compared to providing products and services separately (e.g., Sakao and Lindahl 2015). Nevertheless, as remarked by Neely (2008), companies trying to augment their business through servitization might be exposed to financial difficulties. Thus, when extending service offerings, the associated risks should be taken into account (Benedettini, Neely, Swink 2017). In other words, a financial analysis allows managers to properly design their service delivery process in order to better cope with the risk of unsatisfactory profitability outcomes (Hou and Neely 2017). Therefore, to extend the validity of the proposed research approach, a cost-benefit analysis is needed (Shen et al. 2017).

Furthermore, the proposed modularization approach does not consider the company resources, assuming the modules to be feasible. Hence, in addition to a cost-benefit analysis, a comprehensive feasibility study (i.e. technical, economic, financial, location, manpower analysis) is valuable to validate or modify the proposed service modules in a manner that is beneficial for the manufacturer as well. Moreover, concerning the analysis of the customers' requirements, the use of supporting tools such as the Analytic Hierarchy Process (AHP) or the Fuzzy Logic techniques can certainly augment the effectiveness of the QFD for PSS method (Hara, Arai, and Shimomura 2009; Song et al. 2013). Whereas, the integration of QFD for PSS with the TRIZ method can further reduce the occurrence of conflicts between the product and service elements of a PSS (Song and Sakao 2016). Similarly, the use of tools aimed at quantitatively evaluating the benefits throughout the PSS life cycle from the environmental point of view, e.g. by means of the Life Cycle Assessment (LCA) and the Screening Life Cycle Modelling (SLCM) methods (Fargnoli and Kimura 2006), needs to be addressed. Finally, the flexibility of the proposed procedure needs to be further verified by means of its application in different contexts and industries to validate the results achieved (Yin 2003; Le Dain, Blanco, and Summers 2013).

6. Conclusions

Following the research clues provided by the recent research works on the implementation of PSS solutions, the article proposed a practical methodology to support providers of tangible goods in designing services related to the proper functioning of their products fulfilling customers' needs and expectations. Such an approach, based on the synergic use of QFDforPSS, Axiomatic Design and service blueprint allow engineers to reduce the complexity of addressing requirements in PSS design while maintaining the

PSS's potential of satisfying market demand, diminishing the risk of overdesigning and the generation of design conflicts. The methodology was verified by means of a service modularization for PSSs at a company operating in the biomedical sector. The flexibility of the proposed procedure needs to be further verified by means of its application in different contexts and industries to validate the results achieved. Thus, researchers and practitioners are invited to contribute to its possible further development.

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