Defining a PSS Lifecycle Management System: Main Characteristics and Architectural Impacts

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Abstract. The global crisis and the fierce competition of emerging countries make companies struggling to stay ahead of competition. The number of companies that are enlarging their offer portfolio looking forward to new and increased sources of revenues is always increasing but the number of companies failing in successfully implementing servitization strategy is even more. One possible reason behind this is the lack of tools to support companies while dealing with services that by definition are characterized by high level of intangibility and perishability. In this context, the integration of product design in concurrent with the related service design is becoming very relevant in several industrial fields.

This process is very customer-centered and lead to the development of a product-service specific methodology. Specially, lean design methodologies can be used to foster and improve the integrated product-service design process. Based on this premise, the paper presents the PSS Lean Design methodology developed in the DIVERSITY project and its relations and impact on the data and information management of a product-service lifecycle system. A description of relations and modules customization for the development and diffusion of a PSS lifecycle management system is provided in the paper for an extension also in other contexts.

Keywords: PLMS; Product-Service System (PSS); PSS Lean Design Methodology; PSS Engineering Environment

1   Introduction

In the globalised word, manufacturing companies are nowadays increasingly moving towards the adoption of business models based on the offering of a bundle of product

and service [1]–[3]. This change in their offering is due to the modification of the customers' behaviours and their increasing interest in companies' services [4], [5]. Firms' response to this substantiated into the delivering of a 'Product–Service System' (PSS) through the transformative paradigm of servitization [3], [6]. Despite this proposal, many companies occur in the "service paradox" since the promised value of adding service to existing products is never realized in practice [7].One of the reasons is related to the difficulty in merging products and services not originally designed to be sold together [7], [8]. In fact, the Product-Service engineering discipline suffers the absence of a methodology and a tool with an integrated vision on the products and services design, and able to take into account the requests and inquiries of all the stakeholders [9]. Namely, for a provider proposing a fully customer-oriented solution could imply the PSS's economic unsustainability, while, a provider-oriented solution could signify a failure in meeting the customers' demand [1].

With the scope of overcoming this problem, varied methodologies have been proposed in literature [10], [11]. Although, a comprehensive and holistic framework considering all the elements and actors involved in the PSS lifecycle is still missing [12]–[14]. In this context, the methodology proposed in the DIVERSITY project, the Product-Service System Lean Design Methodology (PSSLDM) [15], [16], aims at surmounting these gaps by defining a new methodology that starting from the needs of all the stakeholders allows the design of product and service features in an integrated way.

Despite this, since the application of a theoretical methodology could result not easily accessible for the companies, mining its day-by-day application, an engineering platform, namely DIVERSITY Platform, to convert the theory into practice has been developed in order to really allow companies in exploiting the expected benefits of PSS [17]. To enhance properly the adoption of a platform supporting the product and service integration a shift in the way product lifecycle data and information are managed is needed.

The adoption of DIVERSITY Platform for the PSS design drives towards a redefinition of the main component of the PLMS (product life cycle management system) traditionally implemented in the manufacturing companies: configuration management, product configurator, PLM workflow modeller, PLM data modeller and requirement management. The introduction of the design of product-service system in manufacturing companies leads to think the management of the information not any more in terms of pure product but in terms of solution structure.

This paper, structured as follows, provides a description of the DIVERSITY Platform, centring then the attention on the PSLM tool, discussing its functional and technological evolution and foreseeing its future developments:

Section 2 discusses the structure of the DIVERSITY Platform, addressing an introductory explanation of the methodology and illustrating its transformation into an engineering environment; Section 3 highlights the rationale behind the PSLM tool, introducing the most important functionalities. Section 4 describes the PSLM tool from a technical point of view. Section 5 concludes the paper summarizing the main results.

2 The DIVERSITY platform

Fig. 1 depicts the methodology developed in the DIVERSITY project, the PSS Lean Design Methodology (PSSLDM), which consists of four phases equally divided into customer-related (the first and the last one) and company-related (the second and the third one). Starting from the monitoring of the KPIs and customer sentiment of the company's offering, the PSSLDM uses the customers' opinion and feedback analysis to identify customer needs (phase 1: Customer Analysis) from which start the conceptualization of the new PSS (phase 2: Solution Concept Design) that, once assessed, is translated into the design of an integrated PSS (phase 3: Solution Final Design). In this phase, the Lean Content Design Rules [18], sets of qualitative DfX guidelines and rules supporting the product design developed in a PSS perspective, are used to support the knowledge management and the integrated design of both service and product features. Finally, the PSS is launched on the market and its performances are monitored in order to identify new possible PSS improvements and new PSS opportunities (phase 4: Offering Analysis). All along the PSS design process a list of Development Process Rules [19], [20], representing indications to be followed by the design team during the project to reduce the wastes in which they can incur are adopted.
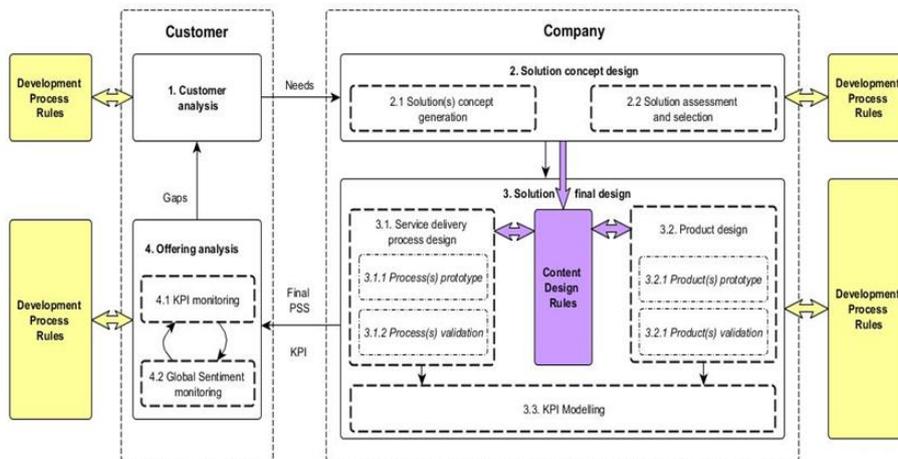

Fig. 1. Product-Service System Lean Design Methodology (PSSLDM)

The DIVERSITY Platform (Fig. 2) consists of a series of dedicated tools that have been developed after the definition of a list of specific industrial driven requirements.

Regarding the first phase of the PSSLDM, the company actor uses
- The *Knowledge Acquisition tool* to store the information coming from the customers and the consumers, this tool has been developed with the scope of being a repository even though it could be modified to suit the firm's needs;

- The *Social Sentiment Analysis tool* with the scope of deeply and qualitatively analyse the opinions collected, and stored in the Knowledge Acquisition tool, and the feedback gathered from the social media platforms;

In the Solution Design Concept phase, the second one, the users are supported by

- The *Product-Service Concept Tree (PSCT) tool* [21], which allows the Design Team to brainstorm on the results of the feedback analysis (the Needs) performed in the previous phase and to identify the related elements to conceptualize the new PSS. To draw the PSCT, besides the Needs, it is essential to identify also the Wishes, the Solutions and the Resources connected to them. After the tree creation, the Design Team is called to evaluate the proposed solutions to identify the most suitable one for the customer Needs and the company exigencies;

The third phase (Solution Final Design) consists of the exploitation of four tools

- *Lean Design Rules tool*, based on the DfX approach this tool is used to support a proper exchange of knowledge and information through the definition of rules between the product and service design phases and to allow a coherent integration of the feature. In particular, the retrieve and definition of the Lean Content Design Rules to be followed by the Designer during the product design phase is made available;
- *PSLM tool* that supports the design starting from the product and service BOM management and, in the platform, constitutes the link between the company proprietary engineering environment and the DIVERSITY one. The characteristics of this tool will be discussed in the next sessions;
- *Service Delivery Process Modelling tool*, used by the Design Team (in particular by the Service manager) to define (with the aid of the BPMN and the blueprinting technique) the service delivery process using the resource identified in the PSCT;
- The *KPI Modelling and Monitoring tool* used to define the list of KPIs to be monitored once the PSS is on the market;

Finally, in the fourth phase, the Design Team is supported by

- The *Social Sentiment Analysis tool*, used also in the first phase to monitor quantitatively the customers' sentiment and support therefore the identification of possible PSS gaps or opportunities which must be considered in the next phase;
- The *KPI Modelling and Monitoring tool*, in here used to monitor the PSS performance on the market and identify possible improvements.
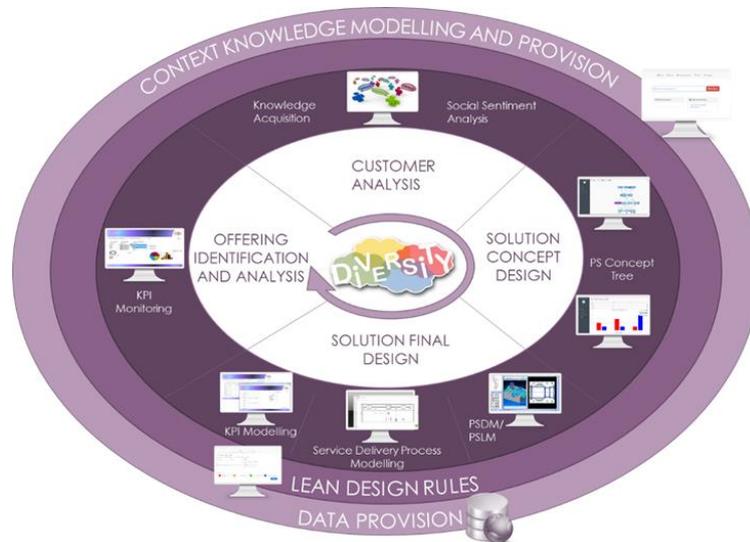
Fig. 2. DIVERSITY Platform

Table 1 shows the correspondences between the DIVERSITY platform's section, the PSSLDM phases and the tools:

Table 1. Correspondence between the platform's sections, the PSSLDM phases and the tools

PSSLDM phase	Platform workflow	Tool
Development process phases	Make It Leaner	Lean Design Rules tool
Customer Analysis	Model KPI	KPI Modelling and Monitoring tool
	Model Sentiment	Knowledge Acquisition tool
		Social Sentiment Analysis tool
Solution Concept Design	Design Concept	Product-Service Concept Tree
	Associate Design Rules	Lean Design Rules tool
Solution Final Design	Design PSS	PSLM tool
	Design Service	Service Delivery Process Modelling tool
	Validate PSS	Lean Design Rules tool
Offering Identification and Analysis	Model KPI	KPI Modelling and Monitoring tool
	Model Sentiment	Social Sentiment Analysis tool

It is possible to notice how some tools are used more than once with different scopes to cover all the aspects of the methodology, this, in order to support the design team during the whole design process. Moreover, this accent even more the flexibility of the DIVERSITY Platform.

In the following sections, the importance of PSLM tool will be stressed out, underlying its role in supporting the integration of product and service design and the integration between the external company proprietary engineering environment and the DIVERSITY Platform from a functional and technological point of view.

3   PSLM tool functional rationale

The design of a PSS requires the involvement of a multi-disciplinary team that needs a system able to manage coherently the PSS configuration toward the development phases of the different components and involves also different methodologies. The definition and implementation of a valid set of authoring and management tool is the preliminary element for a PSS design that track and manage all the issues related to their lifecycle.

The design knowledge is contained on different ICT systems, in this view the PLM systems (PLMS) are the enabling technology for commonly managing the product lifecycle data and information [22] working as an effective authoring and management tool of technical data, information and workflows. PLMS serves as a central hub [23]for product data supporting the collaborative product design and development and the use and management of information in the whole network of actors (i.e. in an extended enterprise) involved in the realization of the product [24]. A PLMS allows to gather the information indirectly connected to the specific product knowledge (e.g. vendor application notes, catalogues, customer feedbacks, marketing plans, archived project schedules, etc.), to chronologically interrelate all the information and to track accesses and data. According to PLM Technology Guide [22], PLMS is very effective to support "innovation, new product development and introduction and product information management from ideation to end of life".

Based on these considerations, the need of development of a PSLM tool is led by: 1) the extension of PLMS through the concepts of PSS development introducing the elements of the PSSLDM methodology; 2) to create an interface between the DIVERSITY Platform and the companies' tools used in the management of the engineering product data (PDM/PLM) that are external to the platform.

According to the first point, the PSLM tool supports the customization of PLMS with a main focalization on the data model extension. This includes the concepts linked with the PSS development that available on the DIVERSITY PSS ontology. Example of this it is the Product-Service System (PSS) concept where the BOM (Bill of Materials) has product and service items. In this context, another new concept is the definition of different service types managing the different characteristics in the attributes' definition. At the service concept is also linked the Service Delivery Model.

The PLMS data model is also enriched with other concepts. For each one of these, there are new item types, new relations among the new item types and new relations among these last ones and the existing item of a PLMS. The introduced item types have a direct association with new lifecycles. A "lifecycle" is a typical object treated in a PLM and used to check the evolution state of the different item types and the configuration rules related to the product structure.

The item types with their relations are part of an integrated Product-Service structure. The BOM generated by the product-service structure is managed in an integrated way and allows to maintain a right configuration along the development phases and to integrate all the linked aspects at the different lifecycles. Based on these assumptions, the validation workflows, which are commonly used to manage in a controlled way the transition between different states of a life cycle, are specified for each item type. It is possible thanks to a collaborative environment where the PSS configuration is guarantee and efficiently managed. A direct consequence is an impact also on requirements management that is extended to include also the requirements related to service development.

The second point leading the development of a PSLM tool is strictly related to the linkage of the DIVERSITY Platform with the companies PDM/PLM where are managed the product data. The PSLM tool has to verify that the external PLM system (i.e. external to the DIVERSITY Engineering Environment) has been modified for managing a PSS development. If this check is positive, the PSLM tool communicates with the external PLMS through a set of services. These last ones are used to share with the PSLM tool the data available on a PLM and vice versa, to save the change on products and services generated during the PSS design tasks. Everything is performed with particular attention to the right configuration structure to be managed.

4 PSLM tool technological features

From a technological point of view, the PSLM tool, is a Java web application built according to Model-Control-View (MVC) design pattern, where the information exchange with the PDM/PLM enterprise systems external to the platform, is carried out through RESTful web services.

The PSLM Tool consists of five main modules, aimed to manage extensions presented above and to interface with these extended systems. These components are:
- *PSS Data Modeller*, which addresses the management of aspects related to the data model of the external PLM system and its extension to incorporate the PSS concepts;
- *PSS Workflow Modeller,* which deals with the management of workflow operating in the PLM system and their interaction with the DIVERSITY solution;
- *PSS Requirements Management*, which manages the product and service requirements;
- *PSS Configuration Management*, which manages the aspects of product and service configuration within the PSS design process;

- *PSS Configurator,* which supports conceptual design phase through the development of PSS configurations based on certain sets of selectable initial conditions.

The software architecture, as previous said, follows the Model-Control-View (MCV) pattern. In detail, the *Controller* has to be implemented specifically to the PDM/PLM interface of the solution available on the market. Through the use of a gateway, all the calls to the correct implementation of the various sub-components, based on the specific case, are assured.

The *Model* and *View* components are PDM/PLM-independent: the entities and the relations that model the enterprise knowledge are platform independent. Even the way to present the information is common, through a usable and independent user interface, hiding to user the complexity inherent the PLM systems.

To test the proper features of the tool, a first implementation was developed by interfacing with an instance of the PLM open source system ARAS Innovator v11, executed on an instance of IIS on a Windows Server 2012 R2. To access the ARAS Innovator and interact with the implemented extensions, custom REST endpoints have been developed using the .NET controls API made available by Aras. These functions, by REST services, allow the achievement of information from extended PLM through the passage of data according to the JSON standard. Those are generic and valid for each installation of ARAS Innovator v11 out-of-the-box to which the proposed modifications were applied, so they are widely reusable.

On request, the information is exposed to the other components of the DIVERSITY Platform through REST endpoints.

5   Conclusions

The paper presented the current gaps in the field of the PSS engineering methodologies, introducing the framework proposed in the DIVERSITY project – the PSSLDM – and the relative Engineering Environment. Besides the mere tools enumeration, when necessary, the information exchange between them has been explained. This led to the definition of the Platform's functioning, emphasising the concept of integrated design for the PSS, and pointing out the importance given to the customers' opinions and companies' necessities in defining market solutions suitable on the functionalities side (for the customers) and on the economic side (for the companies).

The central part of this work focused on the PSLM tool, which extended the conventional PLM tool to include the overall PSS design. In particular, this work outlined why and how this extension has been realized, addressing the main functional and technological points. The PSS Lean Design Methodology supports the PS requirements management definition and the design of the activities to define and later perform the service. Lean Rules are also provided in the methodology to orient the decision-making process suggesting task and check to be performed in the product design. In fact, generally, companies are familiar in the management of data and information of a product lifecycle through PLMS.

The adoption of the PSS Lean Design Methodology to foster an integrated PSS design requires a redefinition of the PLMS main components: configuration management,

product configurator, PLM workflow modeller, PLM data modeller and requirement management. The introduction of the design of PSS in manufacturing companies needs to re-think the common management of the product structure including also service elements and also changing the structure to be adapted in the provision of service. A validation in three steps (one theoretical, and two practical with the platform's early and full prototype) in collaboration with the industrial partners will be performed to solve the issues resulting from the application of the new theoretical approach and the related tool and also to create implementation guidelines to support manufacturing companies along their transformation path to PSS providers.

Acknowledgements

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