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Procedia CIRP 59 (2017) 220 – 226

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The 5th International Conference on Through-life Engineering Services (TESConf 2016)

An Integrated Collaborative Platform for managing Product-Service across their Life Cycle

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Abstract

Product-Service System (PSS) design methodologies have been extensively researched during the past years. Various tools and methods have been established for the incorporation of sustainability and system-oriented lifecycle thinking in the design of PSS. This paper presents an integrated collaborative platform that aspires to conceptualize a new landscape of modular product-services that will be tracked throughout their lifecycle using a network of smart sensors enabling the extraction of useful value. The concept is based on a series of distinct components supported by a common semantic knowledge base, enabling the seamless collaboration of partners of multiple disciplines for the realization of product-services. Moreover, a set of services are used, which are integrated with the sensor network to return information about the performance of the PSS to the customers and the product designer, supporting them in the decision making process. Finally, an application of the proposed methodology in an industrial scenario is presented.

Keywords: Product Service System, Sensory System, Smart Monitoring, Feedback Integration

1. Introduction

Over the last years, sustainability has become one of the key success factors in a new product launch, bringing up the importance of incorporating relevant aspects in the early design phase of products [1]. The reduction of product's environmental impact and the consideration of the whole product lifecycle, being two major sustainability aspects have been lately included in numerous service-related product development concepts [2]. Furthermore, the increased importance of the service sector in industrialized countries has led many manufacturing industries to shift from product- to a service-based economy paradigm [3]. To this end, integrated product-service offerings have emerged, allowing the creation of innovative business models as an effort to increase the competitiveness and subsequently the revenue of industries. The benefits of shifting from products to Product-Service Systems can be also seen by the definition given by Mont. In [4] she defined the Product Service System as a system of products, services, supporting networks and infrastructure that is designed to be competitive, to satisfy customer needs and to have a lower environmental impact than traditional business models This recently emerged concept has forced industries to focus more on the creation of added value from services, bringing into view user-driven business models that incorporate sustainability characteristics in holistic design approaches [5]. The integration of technical support and the provision of industrial services along the entire lifecycle of products are also key points for the viability of industrial product-service offerings [6].

As a result of the so-called servitization of products, the influence, the characteristics of products and services have each other, has grown rapidly, introducing challenges to manufacturing industry beyond the traditional product development and engineering, which are currently not addressed by products and systems. Most of the products in today's market lack of the capability for efficiently adapting to customers' needs, while a limited amount of integrated methods exists for the holistic acquisition and processing of feedback information emanating from product-services by using the concept of performance indicators. The adaptation to customer needs, measured by customer satisfaction indicators, is a characteristic that can be traced to two major factors at the origin of a product: its design and manufacture [7]. Therefore,

doi:10.1016/j.procir.2016.09.009

the adoption of innovative producer-customer relationships is the key to the success of product-service systems design environments.

Addressing the aforementioned issues related to product-services, this paper represents a framework that supports the PSS design, development and evaluation phases. Specific focus is given to KPIs as the main components of the evaluation procedure. Furthermore, a KPI ontology is proposed so as to support the design process.

The remainder of the paper is organised as follows; Section 2 provides a review regarding the design and development methods of PSS that exist in literature. Section 3 presents the proposed framework, its component and the role of the KPIs. Then the use case is described in Section 4. Finally, concluding remarks and future challenged are provided in Section 5.

2. Design and Development of Product-Service systems

The design and development processes of products and services is characterized by a high degree of complexity due to their highly inventive nature. For reducing this complexity several process models have been established supporting developers with recommendations and practical actions. Whereas in classical product development several de facto standards have emerged such, process models for integrated Product-Service system development became a matter of research many years ago [8]. Integrated Product-Service System engineering methods will ensure that the service components will be fully compatible with the product ones. No matter which dimension is more important, product dimension or service dimension, a generic design approach should be capable of handling equally both of them [9]. The evolving process models build on established basic principles of both product development and service engineering and enhance them with Product-Service system-specific characteristics and requirements. The most prominent requirements dedicated to integrated development models are (i) when developing Product-Service systems, product and services are to be handled equally; (ii) to ensure the customer's acceptance, suitable methods of customer requirements management are to be taken into account.

Process models focusing on the design and production of Product-Services systems are provided by [9], [10] and [11]. The process models consider the specific characteristics of Product-Service systems. As characteristics are defined the offerings of a PSS to the customer. In particular, they adjust their efforts to the needs and desires of the customer who is considered as a central element in the provision of Product Service systems. Therefore, there is the customer integration feature in the Table 1 which indicates the customer value that is taken into account during the designing phase of a PSS. Through the analysis performed in Table 1, and following the Collaborative development feature, it is evident that the majority of the existing models neglect the collaborative aspects of the development process.

What is more, environmental aspects which refer to the sustainability factors, that are taken into consideration during the development phase, are also neglected.

Table 1: Consideration of aspects in recent PSS process models

	[17]	[9]	[18]	[19]	[20]	[10]	[11]	[21]	[16]	ICP4Life Platform
Specific Characteristics of PSS	●	●	●	●	●	●	●	●	●	●
Customer Integration	●	●	●	●	●	●	●	◖	◖	●
Collaborative development	○	○	◖	○	○	◖	○	●	●	●
Specific methods	◖	○	○	○	○	◖	○	◖	●	◖
Non-hierarchical networks	○	○	○	○	○	○	○	○	○	○
Environmental aspects	○	○	○	○	○	○	○	○	◖	◖
ICT-systems support	○	○	○	○	○	○	○	○	○	●
Meta-Products integration	○	○	○	○	○	○	○	○	○	●

●Yes ○No ◖Yes but not completely

Another deduction that resulted from the Table 1 was that there is a lack of Information and Communications Technology (ICT) in the product-service. A key drawback of the proposed technologies is the lack of integration of heterogeneous data sources by applying of existing standards, which is the core of a possible solution for the integrated design of products and services [12], [13], [14]. Although significant research work has been performed regarding this subject as well as the development of tools or techniques for integrating the databases of different stakeholders [15], it is focused either on manufacturing enterprises or service providers. Finally, another main drawback of current approaches is the management of Product-Services as an amalgamated product from their conceptual design phase, thus reducing the chance of future integrations through Meta Products, i.e. evolving products, which was not in any of the papers in the Table 1. This is evident even in approaches such as [16] where a three-step module partition process of an integrated Product-Service is presented. This method presents a modular design of the Product-Service, which however is targeting a specific Product-Service.

2.1. Feedback integration

Lifecycle strategies have received increased attention from modern design methods as approaches to accelerate the sustainable value creation through exploiting data from the entire lifecycle of the product [22]. Lifecycle feedback deals with returning usage information of products and services back into the value creation processes of the providers [23]. Going beyond traditional requirements management, feedback management may be sub-divided into product-focused feedback management and user-focused feedback management.

Product-focused feedback has been dealt in many research approaches. The main latest research outcomes focus on the product usage phase for returning product state information to ICT systems and the status tracking of products, especially using condition monitoring [24]. The use of an information feedback assistant agent as a part of a knowledge-based lifecycle management approach for PSS is proposed in [25]. The agent generates and returns usage-based data from the operating phase back in the design and development phases. However, this approach supports the achievement of the desired design goals in a rather conceptual level that is not aligned to the customers' usage behaviour. User-focused feedback addresses the acquisition and integration of customer-centered usage information, such as the end-user perceived quality and other characteristics. A specific approach is described in [26], providing the experience and knowledge of the client as a source for requirements management by extending Quality Function Deployment. In a recent study [27], an operator feedback tool was developed to supplement an automatic multiple sensor data acquisition system assessing the performance of a machine tool. A method that will enable the automatic fusion of sensor data from the machine with actual of user-perceived process performance data is scarce. Furthermore, it has been observed that product usage information is not exploited systematically by existing approaches, since ICT systems lack of widely implemented standards for the processing, analysis and visualization of such data. Today's advanced sensory systems are usually lack of a structured automatic way to transform sensor-based usage data into useful feedback for the design of products. This results in the misalignment between the decisions made in the design phase and the usage behavior of the customers. The concept of Product and User-focused feedbacks play a significant role to both design and usage phases of a product-service offering. To make this statement stronger, examples of the PSSs with the corresponding feedbacks and their exploitation, is necessary and provided in the next paragraph.

Current Product-Services in the form of evolving products can be usually identified in integrated product and meta-product systems. The meta-products are defined as additional components connected to the main product which are going to support engineers in providing new services [28]. Some familiar examples include smartphone kits that utilize mobile device's built-in accelerometer and GPS sensors to track the physical activity of a human. An application running in the device's operating system receives signals from the sensors and provides user-focused feedback like estimation of how many calories the end-user burnt during his/her workout. Another example is that of devices that use Nonintrusive Load Monitoring (NILM) for measuring the electric energy consumption in households. These devices can provide feedback to the Product-Service company and then "intelligent" feedback can be sent back to the end-user, such as estimation of the electric bill or rules for eco-friendly use of the household electric devices. Such products could be upgraded through a set of configurable services capable of exploiting the huge amount of product and user-focused data stemming from different phases of the product's lifecycle. The development of product service though, does not only concern the modularity but also the evaluation of the services through their lifecycle and the improvement of their sustainability. This can be achieved by performance indicators that assess the functionality of the PSS and generate feedback.

For the successful implementation of sustainable product-service systems, the evaluation of the PSS against important key performance indicators (KPIs) throughout the lifecycle of the product-service in necessary. The successful evaluation of the performance of the PSS may prevent continuous PSS design modifications or redesign, resulting in the reduction of cost and lead time of PSS development [29][30]. However, current methods for the evaluation of the PSS design models lack of a method for collecting the most important key performance indicators (KPIs). So as to make the concept of the KPIs more clear, an example is given regarding an Energy Demand Service. This service consists of sensors embedded in devices within an industrial plant and smart meters in the building, which collect data about the power consumption. In this case, the product is the electricity and the KPIs consider the power consumption and the cost of the electricity consumption. Based on the data collected, some recommendations about load balancing are generated and shown to the manufacturer. These recommendations are assessed by the end-user in terms of efficiency and usefulness.

The measurement of the performance of a Product-Service plays also a fundamental role for industrial companies today towards identifying and tracking progress against organizational goals as well as opportunities for improvements. In addition, the evaluation of the system performance against internally and externally defined standards may improve the performance of different stakeholders participating in the organization's value creation chains. Consequently, the design and development of KPI based evaluation mechanisms for continuous monitoring and evaluating the performance of the PSS of the system is mandatory. Nevertheless, the evaluation of sustainability and other relevant indicators of the PSS should be supported by other rule-based mechanisms in order for biased judgements during the analysis of the results to be prevented. Since sustainability is not an intrinsic characteristic of PSS, biased judgements, which does not cover all sustainability dimensions, may lead to poor decisions for the industry [31]. Therefore, the use of weights and rules for the assessment of KPIs have to be carefully selected to match the goals and targets of the PSS. A recently proposed framework [32], uses a performance assessment mechanism that allows the monitoring of end-user experience and product usage state through relevant KPIs. Monitoring contributes to the evaluation of the performance of the implemented processes supporting the customization and (re)engineering of a PSS. The mechanism gathers data from different PSS phases and feeds it back for comparison against defined targets. The assessment phase is based on a Discrete Event Simulation (DES) model that is able to analyze the equilibrium between the quality of the value channelled to the customer and the efficiency of the service processes. The customer value as a driver for the design procedure of PSS engineering model has been also proposed in [33], where the customer is considered in the beginning of the design giving feedback.

The selection of KPIs and relevant methods for measuring the efficiency of a PSS depends highly on the goals and orientation of the evaluation models. The minimization of the total environmental impact has been considered as a top criterion for the evaluation of a PSS performance. Systematic approaches such as the Life cycle assessment (LCA) assess the environmental impact of products along the continuum of a product's life from raw-materials to disposal or recovery [34]. Nevertheless, most well-known LCA methods do not provide specific comprehensive and synthesized results for PSS offerings, a main criterion for selecting an assessment method. Consequently, most methods provide relative results and only for limited number of indicators [31]. Other PSS assessment methods such as [35], [36] and [37] combine LCA with other economic and technical performance measures towards assessing the total value of the product-service developments. A sustainability-oriented value assessment model has been proposed in [38]. The so-called Product-Service Value (PSV) focuses on how product-service design can improve the system's life cycle performance and uses a value graph-based method to interpret value assessment results identifying points of improvement in the product and service configurations.

2.2. Collaborative Design

The communication and distribution of responsibilities among partners and engineering teams of different disciplines is yet another challenging task towards designing a product-service that can create useful value proposition for the market. Cloud-based solutions aiming at tackling the issues generated because of the geographical separation of the teams have been widely proposed in literature, having as purpose the effective exchange of design information [39]. Several effective collaborative design tools have been developed worldwide bringing many advantages to the companies such as the elimination of the need for travelling that may substantially increase the return of investment. Furthermore, in the literature, a number of prototype web-based design platforms that allow engineers at remote locations to collaborate, in real time, during the different design stages such as [10] have emerged. The innovative Collaborative Manufacturing Environment [40] is a noteworthy paradigm that enables the real-time collaboration of multiple dispersed end-users, from the early stages of the conceptual design, for the real-time validation of a product or process, based on navigation, immersion and interaction capabilities.

Frameworks clarifying the organizational responsibilities of different actors have been also proposed for the PSS design development phase [41]. Regarding commercial tools, there are several available that claim they can provide arrange of collaborative functionalities that are based for the most part on the latest Product Data/ Lifecycle management solutions. Nevertheless, they require the support of various applications, tools and information systems that are usually limited in terms of interoperability within the value chain as well as within the boundaries of the different department [42]. In addition, such platforms are not capable of integrating customer's views towards direct customization, which increases the time required in multi-disciplinary projects for the arrangement of a company's infrastructure, such as setting up a new database.

3. Proposed Conceptual Framework

The proposed framework attempts to overcome the identified gaps in the design, development and support of product-services through an under development collaborative web-based platform comprising of three main components. The components are separately dedicated to: (i) the intuitive configuration of different types of products and services by customers of different profiles; (ii) the creation, management and sharing of product and service data by engineers and designers of multiple disciplines, with different backgrounds through the use of a common product-service data model; (iii) the semi-automatic configuration of the suppliers' network and production plan for the realization of the product-service considering critical sustainability aspects of the PSS.

More specifically, the design and customization components of the platform represent two levels of involvement in the design. Initially, product designers, suppliers and service system creators are able to work simultaneously using the available collaborative web-based application offered by the designer component. From this phase the constraints and connection among the products, components and services are defined and provided in an intuitive manner to the customer through the customizer component. Customizer has also the ability to automatically configure and generate interfaces for different end-user profiles. Finally, the planner component uses various evaluation parameters such as the transportation costs and production environmental impact to select the optimum supply chain and production plan configuration. The three main components of the platform are supported by a set of services capable of extracting useful value from different phases of the product lifecycle and providing useful information to the customers through some pre-defined user interfaces. The services can also track critical information of the products, such as its sustainability characteristics through numerous KPIs and return it as feedback to the design phase of the product-service. (Fig. 1). The idea of the Product Lifecycle Management (PLM) which collects useful data and gives feedback to the design phase of the product design was already proposed by the authors in [43][44]. In the current framework, the data acquisition for the functionality assessment of the product is realized through the concept of KPIs which are part of industrial services.

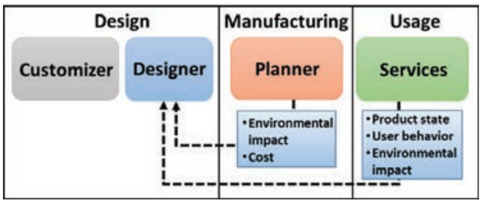

Fig. 1: Feedback integration from different product lifecycle phases in the design of the product-service.

For the design of modular product-services that can meet specific customer needs, a three-layered approach is followed. In the first layer the conceptual design of the configured product-service is realized in terms of geometrical constraints and interfaces. A web-based modeller handles the merging of information provided by product and service designers working on their legacy own tools. The outcome of this process includes a unified semantic description of the meta-products with services. After that, on the second layer, meta-product designers and service providers exchange information, in a common understandable format, for specifying the input data streams coming from products and services and also constraints regarding data handling and feedback management. Finally, in the third layer, the merged semantic description of the product-service is generated, containing the connection between the main product, the meta-products and the services.

As regards the integration of feedback in the design of product-services, a KPI repository has been created for describing the relationships between the product's components and the service modules. The ontology model, providing input to both product designers and customers, consists of KPIs for the feedback management and for extracting information, by defining the relations between product modules and sustainability metrics. The KPIs are oriented to a large variety of product-service systems and one KPI can be also used by more than one PSS. The KPI ontology is able to assess the performance of different product-service aspects throughout the lifecycle of the product and especially its usage phase checking for instance, the remaining useful life of critical components or whether the PSS offering is within the acceptable sustainability margins. As far as the mapping of the KPI results to design information is concerned, predefined rules and axioms are used providing semantic information into design decision support tools (Fig. 2).

More specifically, the feedback mechanism supporting the capturing, classification, analysis, storage and sharing of product-focused data gathers data from two data sources, namely the multi-sensory system and the product itself.

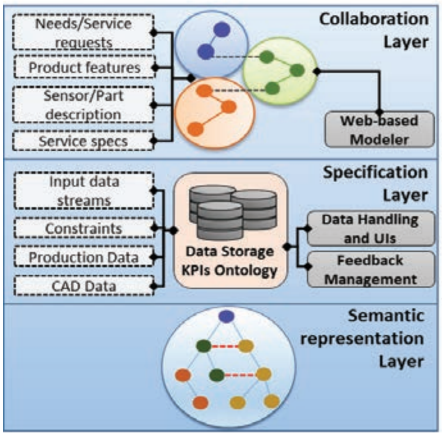

Fig. 2 PSS Design Architecture.

The sensory system consists of the necessary sensors and wireless modules for monitoring and communicating data both for feedback to the customer and for the product manufacturer/ service provider. The monitoring module consists of three components; the sensory system, the data acquisition and the information fusion [44]. Carefully selected sensors are utilized to measure different sources and through a wireless network the data are transmitted to the repository in order to be analysed through an information fusion technique. Finally, the information fusion is used to derive critical product-related information which is directly transferred to the feedback mechanism where data are stored and KPIs assessing the performance of the product are updated (Fig. 3).

The core of the feedback mechanism is the KPI repository, which consists of KPIs created on the basis of the defined relations between the product's components and the sensor modules connected to the product. The KPIs are capable of measuring critical aspects of the product-services, such as the overall performance of the product, the behavior of the end-user and other information that may lead to the improvement of the design and efficiency of the product through the connection of the repository with the feedback mechanism. The KPIs were selected and grouped based on their relevance to the different phases of the Product lifecycle, i.e. design, manufacturing, use, maintenance, etc. In addition, all KPIs are also associated with the economic environmental and social aspects of product-service sustainability. The most important step in the definition and classification of the set of the KPIs used for the PSS performance assessment is the definition of the input sources used for the calculation of a KPI [45]. In [46] a model is presented that uses the structure of ontology models for the definition of the relationships between input data sources and KPIs, enabling the handling and transformation of values from multiple sources into useful information for different levels of production, through the use of metrics (Fig. 4). Metrics are distinguished from KPIs, since they are indicators used as parameters for the calculation of KPIs. The feedback mechanism, using the KPIs values, provides the necessary information either directly to the customers or through a set of rules to the design phase, towards the improvement of the product-service design. Customer receive the updated KPI values through the services they have selected enabling the change of their behavior to improve the performance of the product. The design department receives the relevant results in the form of recommendations or predefined improvement actions that will enable the design of the product-service or its upgrade.

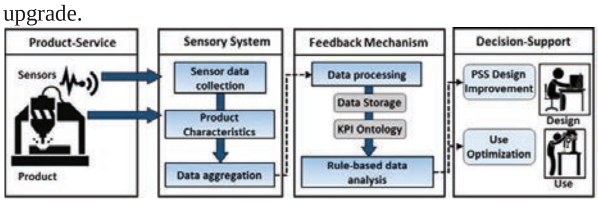

Fig. 3. The proposed data collection and decision making framework

The work presented in this paper proposes a collaborative platform for the design and development of the PSS. Its main components are the Customizer, Designer and Planner and it aims to support the equal handling of the product and service during the design phase. Specific focus is given in the KPI repository and KPI ontology subcomponents, which in combination with the concept of monitoring different sources of data, support the feedback management that affects the customizer and designer components. In order to support the functionality of the platform, two different ICT tool are under development; the monitoring/KPI tool and the feedback mechanism tool which will integrate the aforementioned subcomponents. The tools mentioned above, as well the three main component of the collaborative platform, will be supported by exploiting current technologies but also generating new ideas based on research work. The validation of the tools and components will take place by creating pilot cases in real industrial environments, mold-making and energy supplying industries.

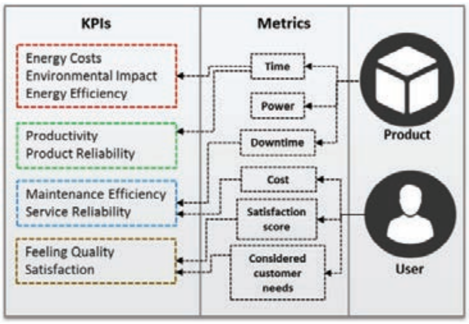

Fig. 4: Connection of input data sources to KPIs.

4. Case study

In order for the utilization of the proposed platform and its functionalities to be demonstrated, a case study is presented below. The actors belong to an equipment manufacturer (OEM) that uses the web-based collaborative platform to design a product-service according to the requirements set by the customer through the customizer component's user interface (Fig. 5).

The customer selects the desired services from a predefined list and indicates certain personalized options concerning the visualization of KPIs, notifications, etc. The requested services deal with the maintenance support, product evolution and monitoring of critical equipment performance indicators. Afterwards, the product designer uses the designer component to configure the requested equipment, which includes sensors for energy monitoring and process fault detection, as well as wireless modules for the extraction and filtering of the collected sensor data. The product designer and the sensor provider work simultaneously on the design and configuration the product-services using the web-based modeller of the component. After the design phases is complete, a production engineer of the OEM uses the planner component to configure the supply of the necessary additional components (e.g. sensors) and plan the final assembly and delivery of the equipment to the customer. The engineer selects the best alternative solution considering criteria such as the environmental impact, time and transport cost.

Finally, the service department of the OEM creates the necessary services and configures the UIs for providing the desired data and updates to the customer. After the equipment is installed in the premises of the customer, the collection of data from a number of services connected to a KPIs ontology model support by a feedback mechanism begins. The product-focused data collected from sensors and wireless modules return as critical information to both the customer and the product manufacturer/service provider through the intelligent feedback mechanism. The returning information give customers a comprehensive view of the machine's performance and health status, enabling them to make informed decisions, such as the replacement of a component reaching its end-of-life or the change of machine production parameters. On the other hand, product designers and production engineers receive both product-focused and user-focused feedback regarding the behaviour of the customers during the usage phase and the overall performance of the machine.

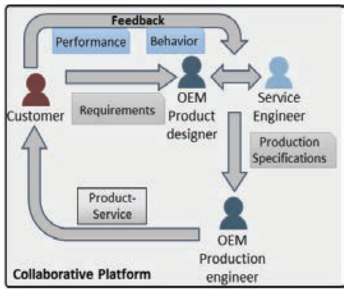

Fig. 5: Information and data flow in the case study.

The service-focused data are collected by relevant applications designed for the end-users who will enter the usability and accuracy of the service results. The corresponding data are provided back to the designer phase so as to improve the current service offered. The feedback is integrated into decision support tools for the design of product-services and is transformed into improvement actions such as (i) the design of the product and service to be aligned to the customers' usage behavior; (ii) the evolution of the machine considering sustainability metrics such the energy consumption, the components' reuse and other middle and end-of-life product characteristics.

The KPIs are measured through multiple sources of data, from applications offered to customers or IT/ICT systems that already exist in the manufacturing company. These data are edited, and either they refer to real or non-real time, they are transported to the components of the platform. The KPI related data used to improve the design phase which also affects the development of the PSS. The use case described above, shows the data flow within the application of the framework. The processes that take place in each of the components, customizer, designer and planner, were fully defined and also the information flow and the evaluation phase with the use of KPIs were also described. In the future, the components and tools will be applied and the results will be provided and assessed.

5. Conclusions and Discussion

This research work presents a collaborative platform that supports customers and multidisciplinary engineer to configure and design product-services that can be monitored throughout their lifecycle to return information concerning the performance of the product-service in terms of energy, environmental impact and quality. To this end, three distinct components are proposed, supported by a set of services returning information to both customers and product-service providers. The proposed platform addresses the current needs of today's manufacturers, providing the faster design of modular products and components, the seamless collaboration of engineers across the value network as well as within the departments of a single company and the reuse of knowledge regarding products, services and processes for new products or upgrades of the existing ones. The proposed platform is supported by a multi-sensory system that is connected to a KPI ontology model through a feedback mechanism to derive useful outcomes for the performance of a product towards improving its operation and design characteristics. Possible challenges that should be addressed in the near future are the compatibility of the platform with open standards, in order to be easier adopted by industries and the automatic provision of middle and end-of-life handling recommendations to the customers.

Acknowledgment

The work presented in this paper is supported by the EU funded research project "ICP4Life – An Integrated Collaborative Platform for Managing the Product-Service Engineering Lifecycle" (Grant agreement no: 636862).

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