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The Impact of Modular Product Architectures in PSS Design: A systematic Literature Review

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Abstract

Changes in customer requirements have led companies to offer not only pure products, but increasingly holistic solutions. These holistic solutions consist of products and services and are called product-service systems (PSS). One possibility to develop PSS is the usage of modular product architectures, as this is an established approach in product design. The aim of this work is to verify the importance of modular product architectures for the development of PSS. For this purpose, the established topics in the field of PSS design will be analyzed with the help of a co-citation analysis and then existing methods for the design of PSS will be evaluated. Finally, the findings are summarized and an outlook on further research topics is given.

Keywords: product-service systems (PSS); design methods; product architecture; modularization; co-citation analysis

1. Introduction

Current megatrends such as globalization or individualization lead to an increasing diversity of demand. In order to fulfil this demand, companies are diversifying their product range to win new customers through an increased external product variety. However, this also increases the internal variety and complexity within the company, which in turn increases the costs for the company in the medium term [1]. In order to counteract the increasing variety-induced complexity, the use of modular product architectures (mPA) has proven to be one efficient option. These kind of product architectures enable companies to configure large numbers of product variants based on a small internal variety. Due to the initial development effort, mPAs are particularly valuable for longer observation periods [2].

As an alternative to increasing the variety of external products, many companies try to differentiate themselves from their competitors by offering and extending services. Services are no longer only seen as an aid for selling products, but also as possible added value. Companies go through a transformation from pure product to solution providers [3]. For the combination of products and services the term *product-service systems (PSS)* has been established in research. As with products, the variety of services offered can lead to increased complexity and thus to higher costs [4].

From a company's perspective, it is useful to combine these two strategies. Companies can differentiate themselves from competitors offering PSS by focussing on mPAs. Modular structured products and services enable companies to offer a wide range of variants and at the same time keep the internal variety for the company diversity to a minimum. For this reason, mPAs should be an important aspect in the development of PSS. This results in the research hypothesis (RH) that which will be tested in this work:

RH: The consideration of modular product architectures is an established research aspect of methodological support for product-service systems design.

The hypothesis will be evaluated in the present work by doing a systematic literature review with a dataset of selected

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articles. The first part of the literature review is a co-citation analysis that is used to identify current research areas in PSS design. The second part is an extended analysis, in which articles that cover PSS design are analyzed in perspective of mPAs. These publications are assessed by using different criteria. In the end a discussion of the findings and an outlook on further research is given.

2. Definitions

The term product architecture describes the combination of the functional structure and the physical components of a product. It also includes the relations between the different elements [1, 5, 6]. An established way to realize product architectures is the development of modular product architectures [1]. Modularity in the context of mPAs is a gradual characteristic that has different properties, for example: component commonality and combinability, function binding, interface standardization and loose couplings [7]. To develop mPAs, two different basic approaches could be found in literature: technical-functional and product-strategic modularization. These two approaches focus on different aspects during the design phase and should both be considered to achieve a modularization that is the optimal solution for the company and not only for a specific department [1].

In literature various definitions of PSS are found. Goedkoop describes PSS as a combination of physical products and services that should equally contribute to the fulfilment of functionality [8]. Similar is the definition of Song, who describes PSS as a solution for customer problems, consisting of integrated physical technological and service elements [9]. Another similar definition is the combination of a product core, enriched by a service shell, that covers the whole product life cycle of the core [10]. Summarizing, the concept of PSS aims at the fulfilment of customers' need and demand. To achieve this aim, tangible products and intangible services are developed and configured to create integral solutions. In recent years, the importance of the subject has increased and PSS development has become a research field on its own [11].

3. Methodological Approach

To evaluate the RH, the first part of the literature review is done with the help of a Scopus® dataset. The applied procedure is shown in Fig. 1. In the first step of the literature analysis the search string is defined. It consists of three terms that could be included in the title, the abstract or the keywords of the documents: *product-service systems*, *design*, *method*. All terms are considered in different variations.

To ensure that the results fit the goal of this work, two limitations are chosen. The first limitation is that the search is limited to the area of (mechanical-)engineering, and the second, that the outcome is limited to articles that are published in journals. The reviewing process of articles in journals and the limitation to the Scopus® database ensure a high quality of the content and limit the results to the most relevant results.

The result of this search contains 137 documents from the years 2003 to 2019. In the next step, all abstracts are screened to check whether the documents fit the topic of this research or not. For example, articles that describe only PSS from a management point of view or focus on production-processes are excluded. In this step the number of articles considered is reduced to 86. With this initial dataset a co-citation analysis is done. The analysis unveils the most frequently cited sources and their relations.

Based on the findings of the co-citation analysis, an extended search for literature is carried out. In particular the methods for PSS design are in focus. The identified methods will then be evaluated according to various criteria.

An analysis with a similar topic as in this work was carried out by Larsen et al. [12]. Larsen et al. analyzed the validation and industry-relation of the method, as well as the basic method steps to develop PSS proposed by the analyzed methods, whereas in this work, the focus is set on the impact of mPA on PSS design. Also, a different procedure, a co-citation analysis, was used to provide a deeper insight into PSS design.

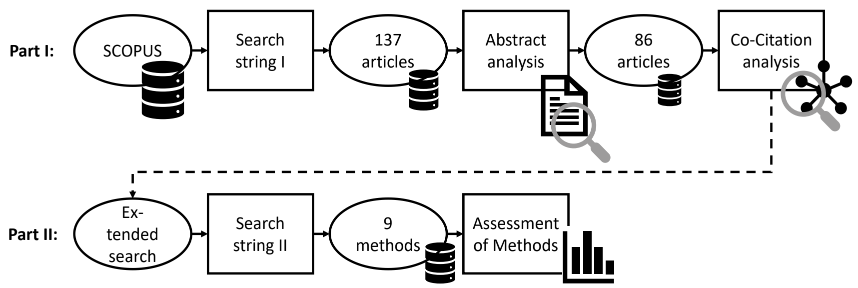

Fig. 1: Procedure to investigate the research hypothesis

4. Co-Citation Analysis

To identify the main topics in current research, a co-citation analysis is conducted. This analysis is a bibliometric method to analyze structures in bibliometric data and describe the relationships between several cited documents. A link between two cited documents exists, if they are cited together by a third document [13]. The co-citation strength is a measure of the association of two cited authors, the more often two authors are cited together, the stronger is their co-citation strength [14].

There are two approaches in co-citation: The first one analyses the co-citation of authors to show the social structures whereas the second approach focuses on the mentioned co-citation of documents [15]. The second approach is used in this work, because it delivers clearer structures, which are needed to investigate the RH.

To carry out the co-citation analysis, the references of the selected 86 articles are analyzed. This is done by using the visualization tool VOSviewer that is able to generate a network out of bibliographic data. This is conducted in three steps. In the first step, a similarity matrix is calculated based on a co-occurrence matrix. In the second step the visualization of similarities mapping technique is applied on the similarity matrix and in the third step the obtained map is translated, reflected and rotated. The result is the map of the bibliographic network containing clusters that, in the case of a co-

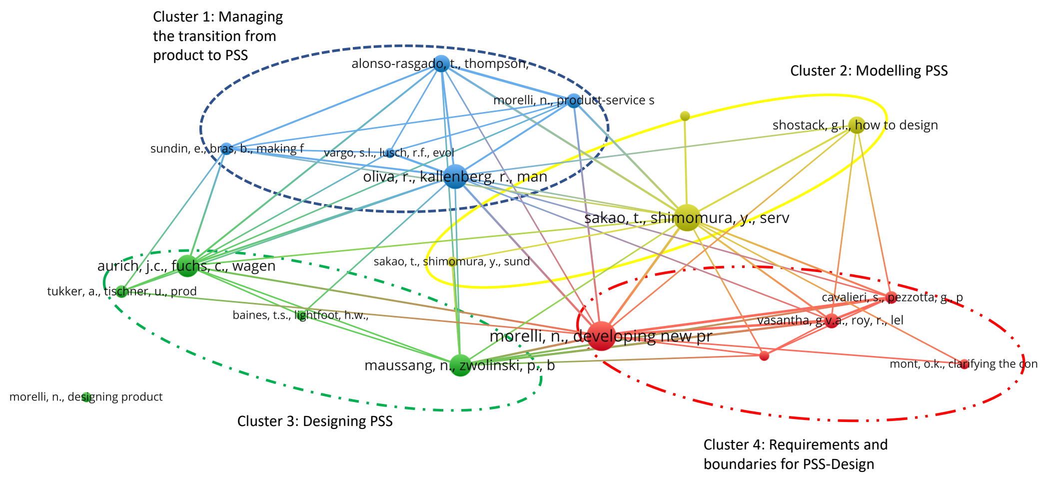

Fig. 2: Visualization of the different clusters

citation analysis, visualize which articles where often cited together [16].

In order to ensure the readability of the network-diagram and to present only the most important sources, a threshold of four is selected. As a consequence, only the references that are cited four times or more in the selected 86 articles are considered in the network-diagram. With this limitation 19 references are visualized (see Fig. 2). In the following paragraphs the four generated clusters will be analyzed in detail.

4.1. Cluster 1 – Managing the transition from product to PSS

The focus of the first cluster is on developing the service from a management point of view. It contains articles focusing on the management of services [17] or on the change in business models and how to manage it [18]. Another topic is the change in economics itself, due to the transition from products to services and the resulting premises [19] and benefits for companies [20]. In [21], a general approach to design PSS is presented.

4.2. Cluster 2 – Modelling PSS

The second cluster covers mainly the modelling and simulation of PSS. Therefore, different modelling techniques are presented which include aspects of simulation and design. The range of topics covers general approaches that visualize relationships between product and services [22] or cover functional performance and reliability [23]. Furthermore, the topic of balancing value and cost when designing the services [24] and a CAD modelling tool is presented that allows designers to simulate the PSS [25]. The overall goal of the publications is to check the feasibility of combining products and services.

4.3. Cluster 3 – Designing PSS

The presented articles of cluster 3 cover the actual PSS design with focus on different design perspectives and give an overview of current research on methodological support for PSS design [11, 26]. Aurich et al. focus on the aspects of process modularization and the consideration of the whole product life cycle [27], while other approaches focus on the visualization of the interaction between different PSS elements [28]. Morelli presents a framework for PSS-design including tools from different disciplines to support designers [29].

4.4. Cluster 4 – Requirements and boundaries for PSS-Design

Cluster 4 covers the challenges in PSS design. Two articles focus on gaps in current PSS research [30] and oncoming challenges [31]. The other articles address boundaries in PSS design and the changes in the design processes in general [10]. In [32], a modelling method is mentioned, that allows engineers and marketers to communicate and work together. General tools for PSS-development are presented in [33].

5. Interim Conclusion

The 19 selected references (see Fig. 2) can be classified into four thematic clusters, dealing with different aspect of PSS. Contextual connections are found for each of the clusters. This proved that by classifying the sources based on common denominations in a publication, it was also possible to show content-related relationships. Nevertheless, depending on the argumentation, individual sources could also be assigned to other clusters in terms of content. Just regarding the content, it could be argued, that [21] should be in cluster 3 instead of cluster 1.

In addition to the clustering of content, the co-citation analysis is used to identify the most frequently mentioned publications. These allow conclusions to be drawn as to which findings can be regarded as established in research. When analyzing the content of the individual clusters and publications, it became clear that mPAs are not mentioned at all. This leads to the assumption that the significance of mPAs in the context of PSS has not yet been recognized and is not yet considered to be one of the standard sources.

In contrast to mPAs, *modularization* in general is mentioned in several publications of the analyzed data set. During the analysis of the articles it was found that in several current publications *modularization* is mentioned as a keyword (see [34–40]). A further finding from the analysis of the keywords is the confirmation of Cavalieri and Pezotta's statement that the terminology is not yet consistent [31]. For instance, 20 variations of spelling PSS could be found in the analyzed data set of 86 publications.

Based on this finding, an extended search is conducted for literature that explicitly contains PSS design methods. Different combinations of the terms *modular, PSS design* and *methods* are applied to various spellings in databases such as

Scopus®, Web of Science® or Google Scholar®. As a result, nine publications are identified, which are analyzed in the following. Afterwards, an evaluation of the publications is carried out to assess the impact of mPA on PSS design methods and to identify existing research gaps.

6. Presentation of Methods and Criteria for Assessment

6.1. Life cycle oriented design of technical Product-Service Systems by Aurich et al.

Aurich et al. [27] present a process for the design of product related technical services. A technical service design process is proposed and various aspects of this process are presented. For example, a process library, used for strengthening the systematical usage of process modules, is presented in more detail. In addition, an interface to existing development processes is described.

6.2. Modularization based design for innovative product-related industrial service by Yu et al.

Yu et al. [41] describe a method for modularization and standardization of service modules. The method consists of five phases: Analysis of market and customer requirements, concept finding for the customers' problems, optimizing business models from a strategic point of view, modularization of services and implementation of the concept as last phase.

6.3. Modular Development of Product Service Systems by Wang et al.

Wang et al. [36] propose a method that can be divided into three parts: functional modularization, product modularization and service modularization, where each focusses on different dimensions of modularity. Based on the so-called product-service planning, service processes and product architectures are derived by a functional modularization. In the following product modularization, the architecture is detailed until possible product variants are obtained. After the product modularization, the service modularization is next. Similar to the products, also services are detailed in the process until the desired output is achieved.

6.4. Module partition process model and method of integrated service product by Li et al.

The method proposed by Li et al. [39] focuses on the product-part of PSS-design. The first step is the service module partition. In this step, the customer's requirements are mapped to service function. Afterwards, the correlation between the service functions based on functions, class and process is defined and the main structure of the services is derived. In the second step, functions and requirements are mapped and the correlation between functions and structure is analyzed. Based on these results, the main structure of physical products is developed. The third step analyses the correlation between the service structure and the physical product, to derive the final module partition of the PSS.

6.5. Applying Platform Design to Improve Product-Service Systems Collaborative Development by Chen et al.

Chen et al. [42] adapt a platform design strategy to improve the PSS-development. The method is divided into three phases. The first phase is concerned with recording the current status of products and services in the company. This is followed by the modularization of the PSS, whereby the user of the method is free to choose which methods he wants to use for modularization. In addition, the interfaces between modules are to be defined. In the last phase, PSS is configured from the modules created.

6.6. Creating service modules for customising product/service systems by extending DSM by Sakao et al.

The first step of the method by Sakao et al. [35] is the description of the customer's needs. In the second step the level of granularity is chosen. This level of detail depends on the results from step one. In the third step the existing service components are collected. The fourth step analyses the interactions between the components. To do so, three different design structure matrices (DSM) could be chosen. Based on the chosen DSM and the interactions, the service components can be clustered to service modules in the fifth step.

6.7. Module division and configuration modelling of CNC product–service system by Sheng et al.

The first step of the method by Sheng et al. [38] aims at designing product modules. To do so, the components are clustered with an algorithm based on the relation between the components over the whole lifecycle. The service modules are developed based on a design structure matrix that includes the relations between different services. To design the PSS, the customers' demands are decomposed into service and product demands and then mapped to the defined modules. Again, with help of an algorithm, the service modules and product modules are clustered and combined to PSS modules. The last step defines rules for the configuration of the developed PSS.

6.8. A customization-oriented framework for design of sustainable product/service system by Song and Sakao

The method proposed by Song and Sakao [37] is divided into four steps. In the first step the requirements of the PSS are identified and analyzed. In the next step, the requirements are transformed into technical attributes and conflicts are resolved. Based on the technical attributes, the PSS is modularized. For this the PSS related components are identified and with help of a modified service blueprinting and are clustered into modules. In the last step, the PSS is configured and a final concept is selected.

6.9. A methodology for module portfolio planning within the service solution layer of a product–service system by Li et al.

Li et al. [43] approach consists of four phases, which are divided into a total of five process steps. In the first step, the requirements for the services are recorded and categorized in step two. Next, the third step is about finding a solution for the requirements that have been included. The individual solutions are then configured and combined into basic solutions. The last step is the evaluation of the service.

6.10. Criteria for Assessment of Methods

Consideration of services and their development must be a crucial part of methods for PSS design and is covered with the criterion *service and service development*. The same applies to the criterion *product and product development*, that is used to assess the product aspects.
It is checked to what extent the analyzed methods take mPAs into account in the PSS design with the criterion *development of mPAs*.

Other important criteria are the two basic modularization strategies: product-strategic and technical-functional. Since a combination of both approaches is preferable in classical product development [1], both strategies should also be taken into account in PSS development. This is considered by the two criteria *technical-functional modularization approach* and *product-strategic modularization approach*.

The criterion *consideration of software as third area* is used to check whether the methods include software as a third area in addition to product and service. Because more and more functions are realized by software, the consideration of it becomes more relevant.

The physical product components and the non-physical service components must work together seamlessly in a PSS. To do so, it is important to clearly specify the interfaces between the components in order to ensure that the product functions correctly [36]. For this reason, the criterion *interfaces between service and product components* is used for evaluation.

Last, with the criterion *concept evaluation of developed PSS*, it is checked whether an evaluation of the created PSS is foreseen in the methods or not. The evaluation is important in order to select the final concept for further processing from several developed concepts. For example, this could be done with approaches mentioned in cluster 2 (see Fig. 2).

7. Assessment and Key Findings

Table 1 shows an overview of the nine assessed methods. The criteria described above are entered in the columns, the evaluated methods in the rows.

The evaluation of the methods shows that no method meets all criteria. This can be attributed to the fact, that the methods presented focus on either products [36–39, 42] or services [27, 35, 41, 43].

Modularization itself is used in different contexts. In [27] it is used to identify parallelizable process steps. Other authors use modularization only for identifying service modules [35, 43].

The development of mPA is focused in some methods [36, 38, 39] or at least mentioned in others [37, 42]. From this it can be concluded that mPAs have an impact on PSS design. However, often only technical-functional modularization methods are used to develop product modules or service modules [35, 38, 39, 41]. Product-strategic aspects, like module drivers, are considered in the modularization process within the subject of sustainability [27, 37, 38, 42], or are not mentioned at all [35, 39, 41, 43]. An exception is usage of interfaces in the context of strategic aspects [36].

The interfaces between product and service are considered very relevant by some authors [36, 41, 42] and are at least mentioned by others [27, 37–39, 43]. The analysis of interfaces is in one approach a method step on its own [42]. For the classification and importance of interfaces, different strategies are mentioned. The interactions and correlations should be analyzed [9, 38], or, as other authors suggest, the interfaces should be used as product-strategic module drivers [36].

What is striking here, however, is that no method addresses the linking of product, service and software, even though many products today, due to digitalization, already contain software for functional fulfillment.

The evaluation of the developed PSS is only described in detail in one article [43]. Here, the focus is on the evaluation of different PSS concepts in the last step of the approach. For this

Table 1: Assessment of Methods

○ not/weakly considered
◐ partially considered
● mainly considered

Assessment of methods	criteria: services and service development	products and product development	development of mPA	technical-functional modularization approach	product-strategic modularization approach	consideration of software as third area	interfaces between service and product components	concept evaluation of developed PSS
Life cycle oriented design of technical Product-Service Systems **Aurich et al. 2006 [27]**	◐	◐	○	◐	◐	○	◐	○
Modularization based design for innovative product-related industrial service **Yu et al. 2008 [41]**	●	○	○	●	○	○	●	○
Modular Development of Product Service Systems **Wang et al. 2011 [36]**	●	●	●	●	○	○	●	○
Module partition process model and method of integrated service product **Li et al. 2012 [39]**	◐	●	●	●	○	○	◐	○
Applying Platform Design to Improve Product-Service Systems Collaborative Development **Chen et al. 2014 [42]**	●	●	◐	●	◐	○	●	○
Creating service modules for customising product/service systems by extending DSM **Sakao et al. 2017 [35]**	●	○	○	●	○	○	○	○
Module division and configuration modelling of CNC product–service system **Sheng et al. 2017 [38]**	●	●	●	◐	◐	○	◐	◐
A customization-oriented framework for design of sustainable product/service system **Song and Sakao 2017 [37]**	●	●	◐	●	◐	○	◐	○
A methodology for module portfolio planning within the service solution layer of a product–service system **Li et al. 2018 [43]**	●	◐	○	◐	○	○	◐	●

purpose, an optimization of customer satisfaction and costs is used. In [38] the developed concepts are evaluated by a suggested modelling-based approach, but it is only used to check the feasibility of the PSS. The other contributions focus on the fundamental development of PSS and leave out the concept selection and evaluation.

The established RH could only be partially confirmed. It is shown, that mPAs are a current topic in PSS design methods and therefore have an impact on PSS design. Nevertheless, mPAs cannot yet be found in the identified four clusters that describe the most relevant research topics.

8. Summary and Outlook

In this work the impact of modular product architectures on PSS design was analyzed by a systematic literature review.

First, a suitable data set was selected using the keywords *product-service systems*, *design* and *method*. Next, a co-citation analysis was conducted based on the found publications. It could be shown, that the clustering on bibliometric data fits to the content of the respective publications. The significance of mPAs in the context of PSS could not be proven, because mPAs cannot yet be found among the standard sources for PSS design methods.

Modular, *PSS design* and *method* were then used as keywords for the second part of the literature review. The methods found were evaluated based on different criteria. It was shown that mPAs have an impact in PSS design, but are not one of the four established main topics in PSS development, so far.

Future research should focus on the development of PSS design methods that connect the design of mPA, with regard to technical-functional and product-strategic modularization approaches. In addition, the specific challenges caused by interfaces between physical and non-physical elements, resulting from the combination of products, services and software, should be considered. Furthermore, a concept evaluation for developed PSS should be included.

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