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STATE OF THE ART OF PRODUCT SERVICE SYSTEM DEVELOPMENT APPROACHES

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Abstract: Sustainability is one of the most important current and future trends. For product-oriented companies, product service systems as a business model innovation are a possible answer to this. Which methods are available to develop PSS and what are the results? To answer this question, the current state of the art is determined, which methods exist to develop product service systems. For this purpose, existing literature is reviewed, with the focus on quality and applicability. In addition, apparent trends will be identified. Finally, an overview of case studies from different industries are given.
Key words: systematic review, product service systems, PSS frameworks, PSS case studies, PSS trends

1 INTRODUCTION

To generate economic growth despite dwindling resources, profit must be separated from resource consumption. The overall picture shows that Romania is ranked 42nd and Germany 6th in the 2019 SDG Index. Both have problems with responsible consumption and production, which are described as "major challenges remain" [1]. Many other countries have similar problems, which leads to new technological innovations but also to new business models (BM) [2–4]. Combined with the opportunities created by digitalisation, connectivity and related technologies, the scope of services offered by companies is increasing [5, 6]. The resulting trend towards servitization leads to purely physical products becoming product-service bundles [7]. These are also called product service systems (PSS), an aggregation of products and services to deliver value propositions to customers [8]. The added service varies over the different phases of the product life cycle [9]. PSSs are enabler to reach new markets and customers. This is also shown by the fact that service has played an increasingly important role in the value creation of companies, since years [10].

The question remains, how companies will react to the shift, from product orientation to service. For this reason, the paper addresses the research question: “Which methods are available to develop PSS and what are the results?”. Therefore, it is important to clarify the definitions and to explore the state of the art of PSS development frameworks. At the end, case studies from various industries will be presented.

1.1 Definitions

Already in 1999 Goedkoop et al. defines a product service system as an aggregation of products and services to deliver value propositions to customers [8]. Meier even includes PSS in the industrial area as a package of product and service components to provide a solution-oriented and value-added approach across the lifecycle [11].
The classification of PSS is also diverse and have already been researched several times (cf. [12, 13]). Mont is divided PSS into product service combinations, services at the point of sale, concepts of product use (use oriented and result oriented), maintenance service and revalorization services [14]. Tukker divided PSS into three

types; function-, availability- and result-oriented-business models [15, 16]. As seen in Figure 1, the types of PSS based on the different proportions of service and product in the bundle.

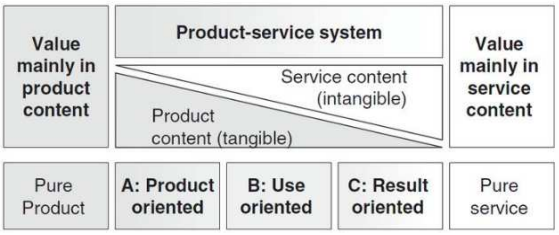

Fig. 1. Types of PSS based on the different proportions of service and product [15]

Meier also makes a similar classification but replaces the “product orientation” in ”function-oriented” [17]. Further to mention is Van Ostaeyen et al. who defined three dimensions of segregated, semi-integrated and fully integrated over the hole life cycle and came up with the of classification of input-based, availability-based, usage-based and performance-based. The last has the three subclassifications of solution-oriented, effect-oriented and demand-oriented [18]. For the sake of completeness, the work of Gassmann should be mentioned, in which he explains, among many others, also innovative BM for PSS [18].

PSS can also serve as an approach to decouple value creation of an increase in resource consumption [19, 20], to combining economic growth and sustainability [15, 21]. Brandstotter even included the sustainability in his definition of PSS, with the addition of "PSS ties to reach the goals of a sustainable development, which means improved economic, environmental and social aspects.” [22].

There are also a variety of definitions when it comes to innovation. For the purpose of this essay, innovation is defined as the entire process of researching, developing and applying a technology. This can be divided into several logically consecutive phases [23]. Based on this definition, the focus is on the process and frameworks for the development of PSS.

1.2 Research Method

Due to the aim to provide a well-founded overview of innovation approaches, rather than to provide a detailed elaboration, a systematic literature review is conducted.

The systemic literature review approach was developed primarily for the medical field [24]. Due to the traceable, scientific, and transparent process [25], this approach leads to more reliable evidence-based results [26]. As a result, the approach is also being applied in more and more areas, see for example [21, 27, 28]. For these reasons, the systemic literature search is considered a suitable method, according to [29, 30].

Due to the objective of providing an overview of the state of the art, a specific literature research, as the conceptual framework, is conducted. In addition, this is the result of initial tests with various search strings, which always produced more than 1000 results, the evaluation of which would go beyond the scope of this essay. Despite the possible exclusion of a few results, the search terms and search criteria are strictly defined:

- Search terms: PSS, product service system, servitization, hybrid service bundles, product service bundles, product as a service.
- Time: not published before 2018
- Language: publication in English will be included
- Publications must have been peer reviewed and accessible
- Subject areas: Multiple test search strings, showed that search terms such as PSS led to many incorrect results because of the frequently used abbreviation of PSS. For example, this is also an abbreviation for polystyrene sulfonate. Thus, the following areas are excluded: Social Sciences, material science and psychology.

Due to the focus on peer reviewed journal publications Scopus by Elsevier as databases was used. The focus is on journal publications to ensure the quality, but without taking the journal ranking into account. To get an overview of the state of the art and, if necessary, to redefine the search terms, a very specific search was carried out first, which returned six results (cf. [31–36]). The following search string was used: TITLE ("state of the art" AND ("PSS" OR "Product service system" OR "hybrid service bundles" OR "product service bundles" OR "product as a service")) AND (LIMIT-TO (PUBSTAGE ,

"final")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018)) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar"))

Some sources could be identified as particularly relevant, as they have by far the most publications in this area (see Figure 2). Thus, the "Journal Of Cleaner Production" have 322 Publications, the "Procedia CIRP" have 254, 187 are Scientific Reports and 102 articles were published in the "International Journal Of Production Research".

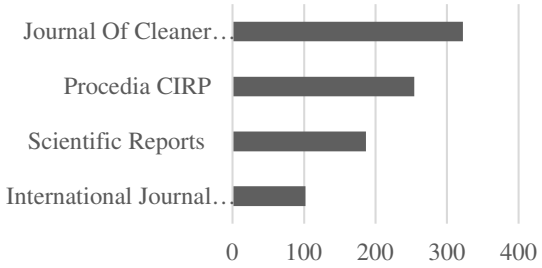

Fig. 2: number of publications by main sources

By taking in a count the keyword of "Product-service Systems" the results could be limited to 362. By reviewing the title and the abstracts these could be minimized to 63.

2 STATE OF THE ART OF PRODUCT SERVCIE SYSTEM DEVELOPMENT APPROACHES

Following, relevant approaches were identified from the results of the systemic literature review. For this purpose, particular attention was paid to the quality and applicability of the approaches. Afterwards some case studies will be presented to show the practical applicability across different industries.

It turned out that Reim et al. [21] did already a literature review on business models and tactics for PSS. With the focus on the development approach, two recent literature reviews could be identified which focus on design methods for PSS. Richter et al. [37] have extracted in 2019 42 methodologies and in 2020, Salwin et al. [36] worked out 60 PPS design methods of which 12 are still used in industry and 21 have been validated in research projects. A comparison of the two reviews shows that the review of Richter et al. focusses on higher quality literature due to the fact that the field application is the main issue of Salwin et al.. Due to the different objectives of both reviews, a good selection of methodologies can be offered by combining them. Due to the priority of validation by already implemented methods, the restriction that publication had to be after 2018 was neglected. By taking in account the identified PSS process models by Richter, that meet the criteria for the definition to process models [38] and these are compared with those of Salwin which are validated in industry or research only three remain which are explained in more detail below.

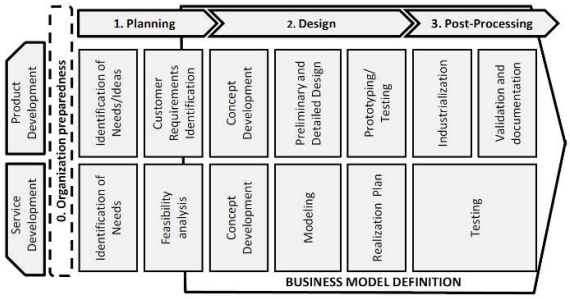

Fig. 3. Integrative development of product and service by Marques et al. [39]

The methodology proposed by Marques et al. [39] considers the integrative development of product and service. As shown in Fig. **3**, the method is, with the integration of the business model, divided into four phases: organizational preparation, planning, design, and post-processing.

The integrative approach requires a change at the organizational level, which creates the preconditions for the PSS. The planning phase captures the customer needs and develops the initial idea. The economic and technical feasibility and the context related customer requirements are evaluated. Based on this, a concept is created as a first step of the design phase. Through several loops of development, validation and testing, a prototype is created after an initial design. Parallel to this the service is designed (cf. [40, 41]). Last but not least the product industrialization as well as the validation and respective documentation are carried out [39].

In comparison, the methodology of Tran & Park [42] focuses on the collaborative redesigning of

PSS. As shown in Fig. **4**, the methodology is based on an outer and an inner cycle.

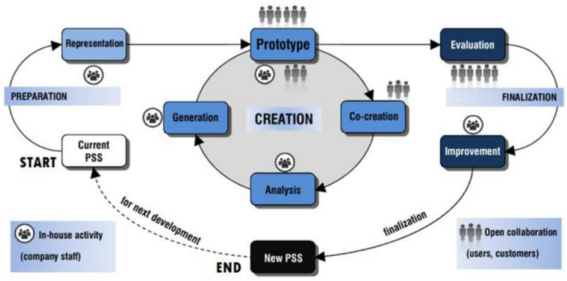

Fig. 4. Co-Creative Framework for redesigning PSS by Tran & Park [42]

The outer cycle starts by presenting the simplest possible version of the PSS to a group of users. Now various needs-oriented options are developed collaborative and improved by the inner cycle. After a suitable PSS prototype has been developed, it is presented to a second user group for evaluation. Subsequently, they improve and finalize the new PSS [42].[1]

The methodology of Kim & Son et al. [44] which is illustrated inFig. 5. Service-oriented PSS development process by Kim & Son et al. [44]., is an fusion of the product development stage-gate process of Cooper et al. [45, 46], the service development process of Brügemann [47] [2] and PSS development projects summarized by Tukker and Tischner [48].

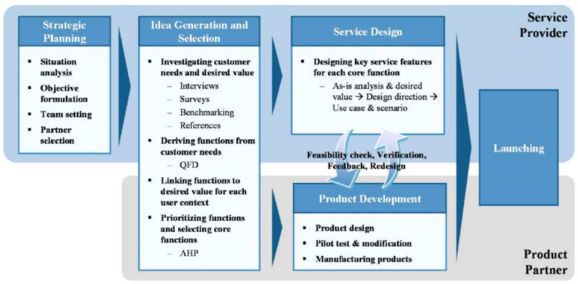

Fig. 5. Service-oriented PSS development process by Kim & Son et al. [44].

The methodology is composed of four stages: strategic planning, idea generation and selection, service design, and product development. A feedback loop is performed between the last two stages. The methodology includes product and service development, whereby it runs sequentially and parallel.

2.1 Possible trends in PSS

Some research directions could be observed during the literature review. The following approaches are particularly worth mentioning here:

- The life cycle management approach as guideline for PSS. Cavalcante et al. identify six PSS lifecycle models [49]. See further [50–55].
- The lean approach as an efficient design method of PSS to match the customer needs. The following steps must be taken into account: customer needs analysis, process prototyping, process validation and to offering identification and analysis [56]. This still represents a research gap [57].
- Modularization as method to manage the contradiction of customization and low costs of PSS [58] where several standardized modules can be combined to an individual PSS, to satisfy the individual customer needs [59]. See further [60–63].

2.2 Selected case studies

A large-scale view among worldwide servitized companies shows, that the most common product-related service is maintenance and support, followed at a distance by retail and distribution, and design and development (see Fig. **6**) [64].

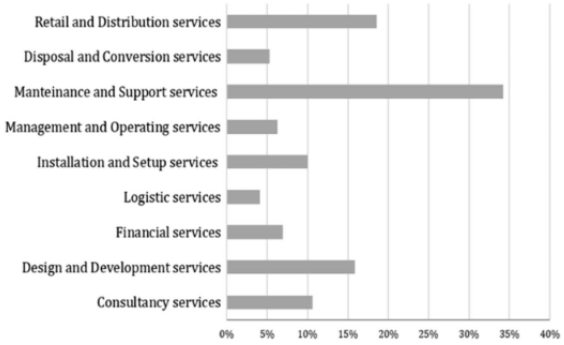

Fig. 6. Distribution of product-related services among servitised companies (72,797 companies) [64]

One of the most common case study is Rolls-Royce's [65]. As an aircraft engine manufacturer, they offer aftermarket-services for its engines, known as “CareServices”. These are distributed via the so-called “CareStore”: “In the CareStore you can select from a broader scope of service

[1] Parallels can be drawn here with the lean approach cf. 43

[2] It is worth mentioning that Brügemann's service development process was only published as master thesis.

solutions than simply maintenance, and include other areas such as availability, efficiency, asset management, transitions, and customer support. Altogether designed to suit your needs at every stage of the engine lifecycle – all fully supported by our advanced digital capabilities".

An overview about cases studies is given in Table 1. For better understanding and for the sake of illustration, a few selected case studies from various industries are presented below.

Table 1

Industrial Smart Service use cases [66]

Application area	Value propositions	Data sets required
Predictive Maintenance	Machine availability Maintenance Cost reductio	Machine data Expert knowledge Simulation data
Production	Human-machine interaction Process optimization	Idle-times Machine data Error dates
Mobility	Navigation Emergency services Ride tracking	GPS Traffic information
Logistic	Supply chain optimization Real-time tracking	Inventory levels GPS User data
Smart Cities	Parking lot finder Multi-platform transportation	Camera videos Parking usage data
Health	Heartbeat tracking Sport assistant Emergency alerts	Heart frequency Patient data Movement da
Innovation Support	Customization Improvement of product quality	Customer information Usage data
Agriculture	Optimization of farming Sustainability	Satellite images Expert knowledge

Digital twin for potato harvesting in agriculture [67]:

The potato harvest is based on the data of the previous year and the experience / estimates of the operators of harvesting machines. Thus, the productivity of each machine depended heavily on the experience of the operator. To improve the quality of the harvested product and minimize waste, a digital twin is created [67]. In this case, a digital twin of the potato is generated by harvesting an "artificial potato" equipped with sensors. This detects the condition of the potato in the surrounding area, which allows the machine to be adjusted [67].

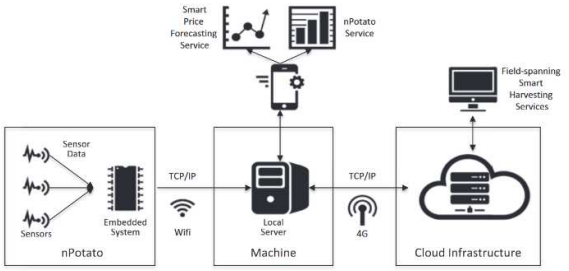

Fig. 7. Potato harvesting PSS [68]

As a business model are listed [69]:

- Service as a free add-on: free service to increase the value of the harvester without generating any direct revenue for the service.
- Purchase option: One-time payment is charged, and the subsequent use of the smart service is free of charge for the farmer.
- Performance-based: Billing can be done per unit of time or per area used.
- Results-based: The quality of the harvest is ensured by the service and the risk of the farmer is shifted to the service provider but for this the harvest must be at least partly automated.

Automotive industry:

The automotive industry is moving more and more toward servitization, with data and communication being the most important enabler. The product is increasingly becoming a factor rather than a separate entity. With the further development of autonomous vehicles, the focus of the PSS is increasingly moving from product to service [70].

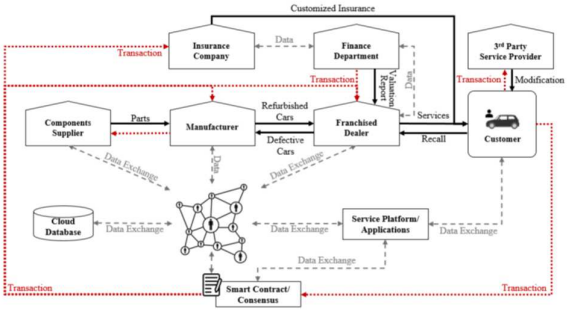

Fig. 8. Vehicle PSS Framework based on blockchain [72]

This allows a variety of services to be offered that go beyond simple maintenance, which is the most common. For example, assisted driving, embedded communication services,

dematerialized car keys and personalization. This results in added value for the customer as well as the OEM [71]. Fig. **8** shows how a vehicle PSS framework could be built in reality. In this case it is an insurance related PSS based on blockchain [72].

Automation systems for residential use [73]:

PSS systems to increase their revenue and customer loyalty, for a product-oriented company of automatic gate and garage systems for residential use and the related equipment (e.g. remote controls, photocells, flagship light). Fig. **9** shows some PSS possibilities. These have been evaluated according to customer value and company value.

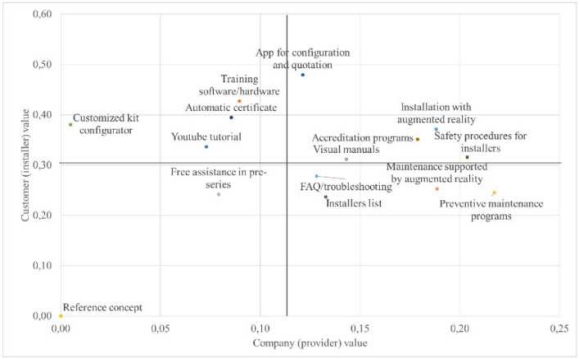

Fig. 9. customer value vs. company value regarding PSS [73]

It can be seen that “installation with augmented reality”, “accreditation programs”, “safety procedures for installers”, “visual manuals” and “app for configuration and quotation” are the most promising cases.

Equipment-as-a-Service in the Machine tool industry [74]:

Similar to the Rolls-Royce's service strategy mentioned above, Trumpf also offers Pay-per-Part. Due to the strategy of Equipment-as-a-Service no equipment purchase is required for customers, they pay only the finished parts they make. In cooperation with Munich Re Group, Trumpf guarantees the output and compensated unplanned downtime. They promote this with: “Economical, Reliable, Flexible, Scalable and Dependable” [74].

Last but not least, SKF is worth to mentioned. They offer PSS, even as parts supplier, and announce that they will soon be able to provide predictive maintenance even based on pure process data [75].

3 CONCLUSION

PSS serves as a sustainable concept by decoupling value creation and increased resource consumption. Here, the share of service and product in the PSS can be expressed differently. However, it is clear that the servitization of industry is progressing, especially due to digitization and the associated technological innovations. The combination of products and services as a package is increasingly less a unique selling proposition than a necessity. They permeate all industries and are very heterogeneous in scope and characteristics.

This is also reflected in the extensive literature on this subject and the many studies on development methodologies and frameworks. Especially the "Journal of Cleaner Production, as well as the “CIRP” conferences are essential publication platforms.

The methodologies are often based on a combination of known and established development methods. In particular, commonalities can be found in the focus on customer needs, feedback loops through prototype evaluation, and the combination of parallel and sequential approaches. In more recent publications, the methods are mainly influenced by life cycle management, lean approach, and modularization. Especially the combination of the last two can be an effective and efficient possibility for a customer based individual design of PSS.

PSS cases can be found in a wide range of designs and industry sectors. Maintenance and support services are the most frequently used services followed at a distance by retail and distribution, and design and development.

In addition to the frameworks, the case studies also show, that PSS is a very interdisciplinary field, combining different disciplines, such as product design, data processing and economic aspects.

Further areas of research would be the consideration of PSS as an answer to shortened product life cycles and the possibility of individualization through modularity. First studies on such frameworks have already been conducted, but there are only few field-tested approaches. In addition, the quantification of the benefits in all three sustainability dimensions in

the dynamic environment of a PSS has been little studied and should be given more attention.

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STADIUL ACTUAL AL ABORDĂRILOR DE DEZVOLTARE A SISTEMELOR PRODUS SERVICIU

Rezumat: Durabilitatea este una dintre cele mai importante tendințe actuale și viitoare. Pentru întreprinderile orientate către produse, sistemele produs serviciu ca inovare a modelului de afaceri sunt un posibil răspuns la acest lucru. Ce metode sunt disponibile pentru dezvoltarea PSS și care sunt rezultatele? Pentru a răspunde la această întrebare, se determină stadiul actual al domeniului, ce metode există pentru dezvoltarea sistemelor produs serviciu. În acest scop, literatura de specialitate existentă este revizuită, cu accent pe calitate și aplicabilitate. În plus, vor fi identificate tendințele aparente. În cele din urmă, se oferă o imagine de ansamblu a studiilor de caz din diferite industrii.

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