Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 70 (2018) 356–361

www.elsevier.com/locate/procedia

28th CIRP Design Conference, May 2018, Nantes, France

The rationale of PSS as an inspiration for Synthetic Environments

R.G.J. Damgrave*, E. Lutters

Laboratory of Design Production and Management, Drienerlolaan 5, 7522NB Enschede, the Netherlands

* Corresponding author. Tel.: +31-53-489-5364. *E-mail address:* r.g.j.damgrave@utwente.nl

Abstract

The use of a Synthetic Environment (SE) in product development cycles is increasing, and the number of potential use situations is expanding. However, predicting the best fitting SE configuration is still mainly based on experience. Proper use of a SE benefits from a product-service system approach, but currently available and developed SEs are often predefined (and rigid) instantiations thereof. Representing SEs as a product-service system is not yet common; the development of new technology is often focused on a predefined set of requirements for a hardware device or a software solution, while the connecting interface is no part of the development. Based on the rationale of product-service systems, more flexibility and robustness in the development and use of Synthetic Environments is explored.
The mutual relations between PSS and SE are the basis for the realization of an overview that provides insight in the dependencies between individual parts of a single system and between complete systems. By making a distinction between the behavior of the system as encountered by the user, and the embedded behavior of the system internally, a different approach for realizing SEs is explained. This approach is not only based on the combination of a product and a service, but also includes experience. This Product Service Experience (PSE) is the foundation for utilizing the rational of PSS in SEs.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.

Keywords: synthetic environments, virtual reality, design rationale, product service systems

1. Introduction

A Synthetic Environment (SE) is a design environment that brings together real and virtual components to allow for adequately experiencing shared information. Therefore, it is not merely a combination of hardware and software, because this would not directly offer something functional to the stakeholders involved. A SE is used to achieve a certain goal; therefore, it rather represents a toolset in which the tools themselves are subordinate to the results of using the tools [1, 2]. As such, a SE facilitates any project phase (by supporting certain activities, enhancing the understanding, improving the experience, enabling the information exchange, etc.) in order to improve the overall process it is a part of.

With the quickly increasing availability of the tools used in a SE - mainly Virtual Reality (VR) and Augmented Reality (AR) tools – and the improving quality of those tools at lower costs, the potential benefits of using Synthetic Environments during the entire product development cycle become more visible. Also due to the increasing acceptance of such tools, the benefits of SEs come within reach for small and medium sized enterprises as well.

Nevertheless, the threshold for completely relying on a SE as a facilitator for parts of the product development process is still high. Therefore, SEs are often seen as additions to currently available tools and methods, but rarely are the inherent and obvious foundation for them. Product development cycles often call for flexibility in the approach and execution of the design process; consequently, they require tools that render predictable results based on non-static use conditions. Predictability is relevant, as it contributes to more robust systems, with foreseeable behavior during any adjustments of the system. Development and use of a SE can benefit from a product-service system approach, but currently available and developed SEs are often rigid and standardized instantiations or reminiscences of the flexibility once intended.

The following is an illustrative example of a current SE to clarify the term ‘SE’: *A 3D virtual representation of a future*

2212-8271
Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.
10.1016/j.procir.2018.02.006

factory, allowing for virtually navigating through the environment. In real-time the configuration and positioning of e.g. machinery can be changed by altering their position in a physical (3d-printed) scale model. Every change directly leads to a new simulation, and to new calculations on different subjects, such as throughput, reliability, costs, maintenance, etc.

Based on the definition of IPSS [3] the tangible product should support the intangible service to achieve a successful PSS. Furthermore, (a part of) the product will not function without the service, and (a part of) the service will not function without the product [4]. Every SE consists of tangible and intangible items; the physical devices are substantiating interaction with the intangible aspects of the solution such as behavior and information. This intrinsic combination of tangible and intangible items shows the inherent dependencies between them, and is one of the major motivations to make use of a PSS approach. Nevertheless, the approach of representing a SE as a product-service system is not common.

Most available professional VR/AR tools are specific to a narrow application area, and can consequently influence only certain phases of the product development process. As a result, the potential market for those tools is small, and the price is high. Due to the constantly decreasing costs [5] of VR/AR equipment aimed at the consumer market, the necessity to know on beforehand exactly which VR/AR tool is suitable for the upcoming process becomes less relevant [1]. Therefore, also smaller companies can take the risk of introducing a SE in their processes. However, selecting and realizing the best fitting SE is still mainly based on experience, and is often influenced by the results of previous use. The developments in the availability of VR/AR tools call for a new fundamental objective in the research field of the development of SE.

Currently, during the development of SEs, the technical specifications are addressed in order to select the right tools, while it can be a better approach to focus on the consequential service to meet the use conditions. The SE always offers a (digital) interaction with the service; this can often be seen as the goal of the user in using the solution. The service is the result of using the solution. This shows that the dependencies between the tangible product for enabling interaction, and the intangible service for providing the results, need attention during the SE development.

Answering the question what SE development can learn from the approach and methodology of PSS [6] is one of the key elements in this research.

2. Rationale of comparing SE-development and PSS

The focus of a SE is not on having merely a tool, but on providing a particular opportunity for the user, and on enabling a certain experience. This can be addressed as a service that is offered to the user, while the SE is just an enabler for the experience (of the service). The added value for the user of a SE is not in the use of a SE itself, but in the consequences of using it. To make the desired experience accessible to the user, the SE comes into play; the SE should realize a (pre-defined) experience, which is tailored during use to the (constantly changing) requirements of the stakeholders.

In this context, the user is not looking for an additional (new) tool or device, but is pursuing a certain goal. The provided service – in the form of a SE – will help the user to realize that goal. With the focus on addressing SE as a product service system, the aim is to use the rationale of PSS to gain more flexibility and robustness in the development and use of SEs. Consequently, in the field of SEs, a distinction should be visible between tool development that focuses on improving a single asset (e.g. VR/AR hardware, software, information management, …) and on developments that focus on providing a complete integrated experience by means of a SE.

Currently, the development of new (VR/AR) tools is often focused on a predefined set of requirements for a single hardware device or a software solution, while the connecting interfaces between various hardware and software platforms is not part of the development. Being able to integrate new tools seamlessly in SEs for product development often requires conscious amendments of the system. This results in the demand for tailor-fit solutions, while requiring craftsmanship for development and use.

By reviewing the common characteristics between SE and PSS from a high-level perspective, similarities come forward on aspects where developers of a SE can use the experience and expertise available in the field of PSS [7]. There, the interfaces between different physical and non-physical attributes are already seen as one of the main pillars for a successful solution, while in SE development they are typically seen as a necessary evil. Changing this approach requires a different view on how to develop a SE. The current focus in the development of SEs is often on selecting the best fitting hardware and software, while in a PSS approach, the resulting service (defined by functional specifications) is leading and the enabling hardware and software are only treated as interfaces or assets to achieve the experience [8].

In a PSS the resulting service is always a combination of multiple resources achieving a certain goal by working together and controlled by multiple stakeholders [9]. This also applies for SEs; any SEs require the combination of the following nine

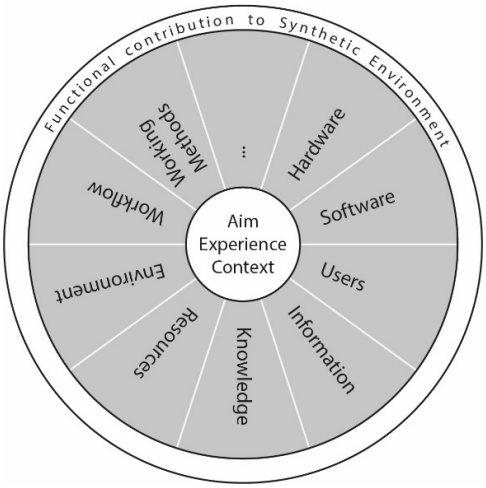

Fig. 1. Blueprint of the configuration of a SE.

aspects to achieve its goal [1] as visualized in figure 1. The challenge is to find the most appropriate combination of these aspects.

2.1. Identifying SEs as a PSS

The nine elements in the middle circle of figure 1 form the base of a SE, while none of them is leading. All should be balanced during the development in order to achieve the best possible service and experience. Therefore, the focus should shift towards the interfaces between them, while maintaining the quality of individual items. The challenge here is to provide the maximum flexibility of the system, with a predictable and guaranteed robustness of the service experienced. This approach has the danger of a loss of focus due to the broad expertise needed by the developers.

Previously, this was difficult to achieve within the SE developments because many individual VR/AR tools required expertise, or even craftsmanship. Due to the improved accessibility and lowered threshold for use, it is now also possible to combine VR/AR tools without having to be an expert in each individual field, while also the (financial) risk is lower. This creates the possibility to shift the focus to an interface-oriented approach; precisely the area in which PSSs excel.

A SE can serve multiple goals for various stakeholders. The user of a SE has a specific purpose in mind, and in order to achieve that purpose, a particular experience is desirable. This experience is presented in the context of the user. The gap between on the one hand the aim, experience and context of the stakeholder, and on the other hand the final SE, is reconciled with the aspects that are part of the SE. There is always the need to use these aspects in order to achieve the purpose and desired experience in the stated context with use of the SE. Configuring solutions to fill this gap between the expected experience of the user and the provided behavior is commensurable with the rationale of PSS. This similarity concedes the validity of utilizing the knowledge and skills of PSS in the methodology of SE development. To realize a properly working and most appropriate result, all requirements can first be translated into what will be documented in the blueprint.

The similar challenges in the approaches for the development of SE and the PSS approaches lead to the identification of reciprocal relations. The experience and expertise of current and upcoming PSSs give the opportunity to streamline future SE developments [10]. Within this research, the impetus is also on facilitating and stimulating the use of the PSS rational for developers of a SE during the complete lifecycle [11, 12], and not solely for the experience of the end user.

3. Addressing SEs as a PSS

The aim is to use the rationale of PSSs to gain more flexibility and robustness in the development and use of SEs. To make optimal use of available and new VR/AR tools in the near future, the emphasis of this approach will be to work towards a system of systems. In this system of a systems, the SE can be seen as a fully operational system, while the configuration of the SE can consist of multiple independent systems not perceivable for the end user (e.g. VR/AR tools). Hardware and software can still be developed separately, but a flexible and adjustable interface is necessary for connecting the two. Dependencies between individual parts and between complete systems should be made more visible and understandable. Dependencies should not be handled as boundaries or restrictions, but can be handled as opportunities for reinforcing the system and can be used to understand the robustness of the solution.

Flexibility becomes inherent to future SEs if the solutions aim to use the continuously evolving technology, especially as the developments in hardware and software are faster than the lifespan of a SE. Furthermore, the information in the system will constantly change, as will adjacent systems or solutions. Taking this into consideration, the only way to provide and guarantee a result is to focus on the interconnecting elements of the system, and the expected experience for the user.

To increase the robustness of a SE, the consequences of a new SE (or changes to an existing SE) should be more predictable. This can only be achieved if the effects of changes in the configuration of the complete solution can assimilated by the SE. To achieve such resilience, any changes need to be made transparent to all elements at the various levels of aggregation. Thus, it is necessary to define the functional specification of each element of the solution [13], and subsequently the relation it has with other elements. These relations can, for example, consist of receiving input, providing output or controlling other elements.

Especially when the focus is on delivering a complete system, the user should not be concerned with choices on the underlying enabling aspects like hardware and software solutions. Firstly, the user is no expert in the field of designing and developing a SE, and secondly, the user is not capable of keeping an overview of dependencies between elements of the solution from all the perspectives involved. As an example, this can be compared to using a copier: the user does not have to know the composition of the technical parts of the copier, he only has to be able to use it. At the same time, maintenance of the copier has to be addressed, but preferably not when the user quickly needs one copy.

In an adequate PSS, the user is not forced to make a distinction between a service or a product. The system is experienced as a whole, and for the user it is not necessary to know if a tangible product or an intangible service is responsible for providing that experience. This perspective is often neglected in the development of a SE, which results in emphasizing the relation between a product and a service. Through this, the user loses overview of how the SE responds to the interaction provided, and can experience the feeling of not being in control. A PSS is aimed more at providing an experience than on product use, during the configuration of the PSS each element in the SE should therefore be treated as an enabler of possibilities. The challenge is to provide an experience to the user that is, as good as possible, in line with the expectations. At the same time, the management aspects of the PSS should be considered during the appraisal. These aspects aim for optimizing the efforts involved in ensuring the perceived quality of the PSS [14], irrespective of whether the

SE is a product oriented, use oriented or results oriented PSS [15].

Configuring solutions to fill the gap between the expected experience of the user and the provided behavior by the SE is commensurable with the rationale of PSS. This similarity concedes the validity of utilizing the knowledge and skills of PSS in the methodology of SE development.

4. Resulting approach

The use of a SE can become much more effective and purposeful if the user experience is explicitly involved and addressed. After all, the use of SEs in development trajectories is predominantly instigated by a desired experience. As such, the combination of products and services in the field of VR/AR only provides added value when the experience is an inherent part of the system. Therefore, from the perspective of the user, a SE should not be referred to as a PSS but rather as a product service experience (PSE). A mode for this PSE, originating from the observations in the previous sections is shown in figure 2.

4.1. Product Service Experience

All three parts of a PSE (Product, Service & Experience) have a certain overlap, while influencing each other. For example, every user has his own opinion on what a physical product looks like, this experience of a tangible item can influence the way the user encounters the whole behavior of a system. The same can be said about how a digital service (e.g. digital interface) can influence the quality perception of a tangible item. The experience of the user exceeds what the SE will offer; there is always a certain interference with the real world. The relevance of the overlap between these areas can differ amongst different PSEs. The overlap of the experience can be shifted more on the product part or on the service part, but this should not influence the complete experience. This overlap and borders are not relevant nor important for the user, as the user can access the PSE as a whole. The user is actually an essential constituent of the PSE. After all, without the user, nobody is experiencing the PSE, so it no longer is a PSE. The overlaps are the parts of the PSE that require insight and overview about relations and interdependencies between the different parts. These overlap areas are the essentials that make the combination between product, service and experience encountered as an integrated and cohesive solution. The model can also act as a simplified profile of the solution, to make it easier comparable to other solutions, or to find more adjacent solutions based on a similar overlap.

4.2. PSE behavior

Stakeholders of a PSE have to be facilitated and stimulated to use the blueprint of figure 1 for documenting their needs, and for reviewing the status and possibilities. This blueprint provides an overview about the different elements that must work together to deliver an experience. Two types of communication can be distinguished; first the communication between different (VR/AR) tools and devices that function as an enabler; this is the internal communication. Secondly the input from the user and external stakeholders towards the PSE. Communication between the PSE and the user is essential in order to tailor the service to the expectations of the user. This can be seen as external communication.

This internal and external communication of a SE results in two types of behavior:

- Embedded behavior
  The behavior of the internal systems, not noticeable to the end user. E.g. the synchronization of physical devices that act as a whole, such as the visual and aural feedback.

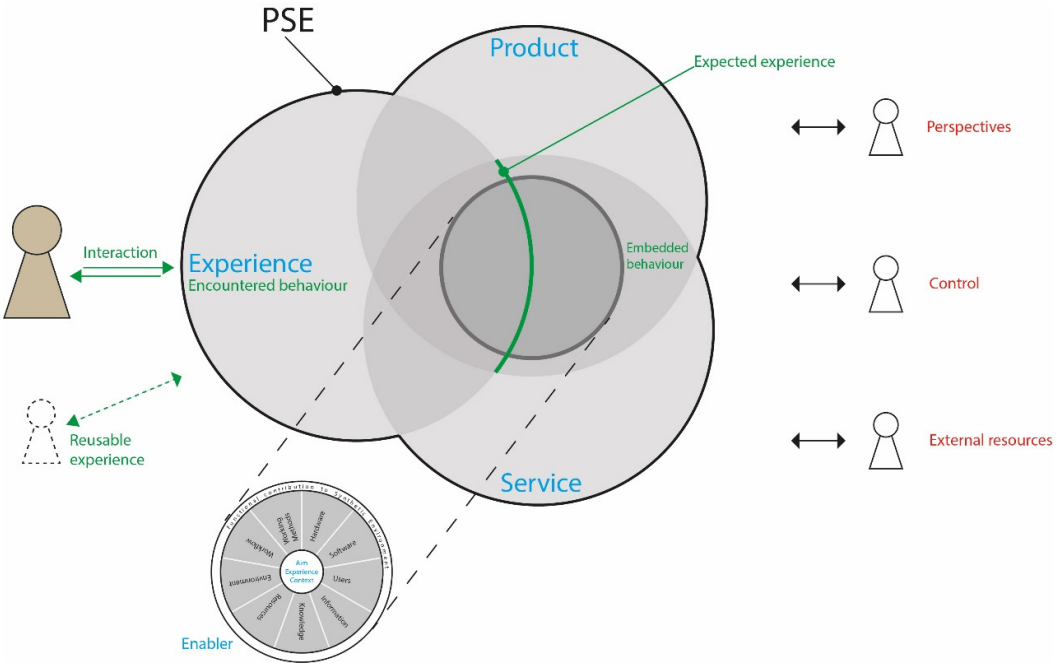

Fig. 2. The product service experience (PSE) overview.

- Encountered behavior
  The behavior encounterable for the end user, resulting in the experience of the service. E.g. the hearing of the sound and the seeing of the screen.

The PSE model is aimed at creating a better conversion of the functional specification into an encountered behavior, where the focus is not on a product, or on a service, nor on the combination of both; it rather is on the desired experience. This experience is directly influenced by the interaction with the user. The encountered experience is the reason why anyone would use a SE in product development trajectories, and should therefore be accentuated. Subsequently, this experience should offer something not possible without having the SE.

The tailored experience of a PSE can cause that different users of the same system experience a different solution. The embedded behavior of the PSE is the combined result of the product (tangible) and the service (intangible). The embedded behavior is not experienced by the user; it is the unnoted collaboration between the different elements that form the solution. Some aspects of the behavior will be encountered by the user; this renders the combination between the product, service and the user. This encountered behavior is also the result of the users' interaction with the system.

The expected experience is what the designer/developer of the PSE would like to give as an experience to the user. This is the boundary between the behavior not noticeable to the user, and the actual experience of the user. The user experience is something that will (and must) dissolve after use, since every experience is the result of an individual user encountering the PSE. Part of the solution for this is to use the functional specifications as the expected experience, and use that approach to bridge the gap between anticipated experience and the embedded behavior.

The selected VR/AR tools in the PSE are the enabler for experiencing the product service combination. The different aspects can exchange data with each other inside the PSE. This is the part of the PSE on the right side of the expected experience line in figure 2. The product and the service can respond to each other without influencing the experience. Although the experience will evaporate for each user after use, it can be experienced multiple times. The encountered behavior can still be the same, while the enabling system has changed. Interaction can be used to tailor the experience, and by capturing the effects of changes in the system to the encountered behavior, the PSE can give insight in which configuration leads to a best practice situation. This control system checks if the expected experience overlaps enough with the encountered experience. This approach can be used to improve the predictability of future solutions.

5. Expected impact

In order to develop SEs from the PSE point of view, the emphasis will be on the relationship between the various elements (tangible and non-tangible) to close the gap between the user and the SE on top of on the development of individual elements. In addition, the functional specifications defined by the user will be leading in the development of the SE, and in the underpinning of choices. To be able to steer on this, a consultation model is needed in which the multi-stakeholder decision-making processes are supported and facilitated.

Having a model to keep an overview of the entire PSE is desirable [16, 17], since it results in a combination of multiple disciplines and expertise. The communication and dependencies between these different areas of expertise need to be emphasized; which is similar to the emphasis on the dependence between the different elements within the PSE.

A PSE must be considered as a tool, and not direct as a solution. The PSE is therefore an enabler for the user. As stated before, the focus on a PSS approach for SE development and use lies with the interfaces between the different aspects of the solution. All these different aspects can also contain multiple elements (e.g. multiple hardware items or multiple software items in one SE). All these elements have to work together in order to make the solution work [18]. The PSE is the representation of the combination of all SE aspects both in the product as well as in the service domain. This enables the interaction, adhering to the expected experience (reference) and constituting embodied or embedded behavior.

A PSE can also be influenced by external factors that act as an external resource, have a different perspective on the PSS and/or can control (parts of) the SE. These external factors can for example be the reason for the adjustments in the SE to make it more tailored to the user, or for adding products or services from other sources into this SE. The view on the PSE from these external factors gives a different perspective on how the PSE functions; the PSE should perform according to the specifications from that stakeholder, in order to ensure that there is as little difference as possible between the expected experience and the encountered behavior. The view from this perspective is focused on the expectations of possibilities, while the focus of the user lies at what is expected to encounter.

The PSE model provides the stakeholders a tool to achieve an overview of the PSE by reviewing, annotating and documenting the results of a PSE. This overview can be used to communicate and archive the different configuration, in order to learn from experiences from the past. This all is aimed at improving the predictability of a PSE.

5.1. Understanding relations

By making use of the previously mentioned PSE model an attempt is made to achieve more insight in the interdependencies in the development of a SE. The main reason to adopt the rationale of PSS in the development of a SE is the need for more understanding of the relations between the different elements that form a SE and the resulting experience.

This can prevent the development of a SE to enter a problematic status quo, wherein it is not clear what the needs for a SE are, and thus too much functionality is put into the solution. This abundance of functionality often works against the maintainability of the PSE, since it remains unclear which part of the SE will be used and what the consequences of that use will be.

In addition, to make it more transparent where the vulnerabilities of a solution are, a PSE offers an overview of the dependencies of a system. These dependencies can also be

mapped on existing solutions, but with the PSE approach, as they are an inherent part of the development. These dependencies can be used to cycle through (worst case) scenarios, but also make it possible to switch quickly to an alternative solution in the event of a fault. An overview of dependencies also provides insight into areas that are more vulnerable than others (e.g. due to more dependencies); this can all be considered when realizing backup systems. More robustness can be achieved by knowing the position of the dividing line of expected experience between the embedded behavior and encountered behavior of a SE. This allows developers to gain more understanding of internal and external relationships of the SE.

6. Concluding remarks

The number of consumer-oriented VR/AR tools is tremendously increasing, making the availability of off-the-shelf products larger than ever before. Correspondingly, the need to deploy custom made equipment in a SE decreases. Initially, the challenge was to develop the best technology possible to fit the purpose of the solution. Now, it is increasingly relevant to configure the best possible solution from the ever-expanding offer of contributors.

By adding the ‘experience’ to a SE more understanding on the impact of a solution can be achieved. Knowing the position of the dividing line of expected experience between the embedded behavior and encountered behavior of a PSE, will lead to gain more understanding of internal and external relationships of the (components of the) SE.

By focusing on the overall combination and overlap between product, service and experience, a tool is presented that can increase the quality and predictability of a PSE. The position of a SE in the overlap between these three fields provides developers more predictable results, while the borders fade for the user.

It is expected that with the support of the proposed PSE model more predictable SE can be developed, but further studies will be needed to find the limits and requirements of use.

References

[1] Damgrave RGJ, Lutters D, Van Houten FJAM. The Virtual Reality Lab as a Synthetic Environment: From Strategic Approach to Practical Implement. In: Abramovici M, Stark R, editors. Smart Product Engineering: Proceedings of the 23rd CIRP Design Conference, Bochum, Germany, March 11th - 13th, 2013. Berlin, Heidelberg: Springer Berlin Heidelberg; 2013. p. 787-94.

[2] Meijer F, van den Broek EL, Schouten TE, Damgrave RGJ, de Ridder H. Synthetic Environments as visualization method for product design. Proc Spie. 2010;7527:752712--10.

[3] Meier H. Industrial Product-Service System. In: Laperrière L, Reinhart G, editors. CIRP Encyclopedia of Production Engineering: Springer Berlin Heidelberg; 2014. p. 696-700.

[4] Boehm M, Thomas O. Looking beyond the rim of one's teacup: a multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. Journal of Cleaner Production. 2013;51:245-60.

[5] Bowman DA, McMahan RP. Virtual Reality: How Much Immersion Is Enough? Computer. 2007;40:36-43.

[6] Meier H, Roy R, Seliger G. Industrial Product-Service Systems—IPS2. CIRP Annals - Manufacturing Technology. 2010;59:607-27.

[7] Nguyen HN, Exner K, Schnürmacher C, Stark R. Operationalizing IPS2 Development Process: A method for Realizing IPS2 Developments based on Process-based Project Planning. Procedia CIRP. 2014;16:217-22.

[8] Nemoto Y, Uei K, Sato K, Shimomura Y. A Context-based Requirements Analysis Method for PSS Design. Procedia CIRP. 2015;30:42-7.

[9] Moser U, Maisenbacher S, Kasperek D, Maurer M. Definition of an Approach for the Development of Product-Service Systems. Procedia CIRP. 2015;30:18-23.

[10] Marilungo E, Peruzzini M, Germani M. An Integrated Method to Support PSS Designwithin the Virtual Enterprise. Procedia CIRP. 2015;30:54-9.

[11] Wiesner S, Freitag M, Westphal I, Thoben K. Interactions between Service and Product Lifecycle Management. Procedia CIRP. 2015;30:36-41.

[12] Nguyen HN, Schnürmacher C, Stark R. Research on How to Introduce the PSS Engineering into Industry. Procedia CIRP. 2014;16:74-9.

[13] Damgrave RGJ, Lutters D, Drukker JW. Rationalizing Virtual Reality based on Manufacturing Paradigms. Procedia CIRP. 2014;21:264-9.

[14] Sassanelli C, Pezzotta G, Rossi M, Terzi S, Cavalieri S. Towards a Lean Product Service Systems (PSS) Design: State of the Art, Opportunities and Challenges. Procedia CIRP. 2015;30:191-6.

[15] Tukker A. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment. 2004;13:246-60.

[16] Exner K, Stark R. Validation of Product-service Systems in Virtual Reality. Procedia CIRP. 2015;30:96-101.

[17] Exner K, Lindow K, Buchholz C, Stark R. Validation of Product-Service Systems – A Prototyping Approach. Procedia CIRP. 2014;16:68-73.

[18] Damgrave RGJ, Lutters D, Thalen JP. Selecting Virtual Reality Tools in relation with their use context. In: ElMaraghy HA, editor. Enabling Manufacturing Competitiveness and Economic Sustainability: Springer Berlin Heidelberg; 2012. p. 269-74.