21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

COPING WITH THE CHALLENGES OF ENGINEERING SMART PRODUCT SERVICE SYSTEMS - DEMANDS FOR RESEARCH INFRASTRUCTURE

Kuhlenkötter, Bernd; Bender, Beate; Wilkens, Uta; Abramovici, Michael; Göbel, Jens Christian; Herzog, Michael; Hypki, Alfred; Lenkenhoff, Kay
Ruhr University Bochum, Germany

Abstract

Driven by innovations of information and communication technologies as well as increasingly demanding customer expectations on individualized products and services Smart Product Service Systems become success factors for any enterprise acting on a globalized market. Increasing product complexity on the one hand as well as flexible autonomous (re)configurations and adaptations throughout the entire product lifecycle on the other hand call for dedicated research methodologies on supporting the inter- and mulitdisciplinary engineering process. Active experimentation and simulation of typical Smart PSS lifecycle situations are key to developing new methodologies. The approach specifically fosters the integration of customers into all steps of the engineering process, which is again key to meeting the characteristically interdisciplinary requirements to Smart PSS. On this basis, the paper outlines the scientific concept of an Interdisciplinary Research Center on Engineering Smart Product Service Systems jointly funded by the federal government of Germany as well as the state government of North Rhine-Westphalia.

Keywords: Product-Service Systems (PSS), Service design, Multi- / Cross- / Trans-disciplinary processes, Virtual Engineering (VE), Research methodologies and methods

Contact:
Prof. Dr.-Ing. Beate Bender
Ruhr University Bochum
Lehrstuhl für Produktentwicklung
Germany
bender@lpe.rub.de

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 3: Product, Services and Systems Design, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

Recent achievements of information and communication technologies are taking their way into traditional industries, changing products, processes, organizations, business models and whole value chains with enormous speed and thus increasingly gain access to our private and professional everyday life. "Smart Products" are expanded by the integration of services into so-called Smart Product Service Systems (Smart PSS). Driven by embedded electronics and software, multi-sensor systems and integrated actuators, these systems communicate with each other, implement integration and adaptation processes at component and system level autonomously - so these systems are offering added values to customers as well as to providers that cannot be estimated entirely in early lifecycle phases. Examples can be found in automation engineering (e.g. industrial robotics), in the area of mobility (e.g. car-2-car communication) and in medical technology. The complexity of these new product categories, the conceptual integration of services, as well as the definition of associated business models requires fundamentally different approaches compared to traditional product and business development. A clear dissociation of both defined life cycle phases as well as domain specific work organisation becomes increasingly difficult. This also shifts value creation from production to product development (Baars and Lasi, 2016). In this context, virtual product twins serve as a base for smart engineering and smart production of individualized, autonomous and highly connective product service and additionally allow for the early validation and verification of product properties. Moreover, value creation of Smart PSS takes place in ecosystems with multiple stakeholders playing multiple roles, which is difficult to transfer into applicable business models (Mougaard, 2016). The disruptive nature that goes along with these highly innovative products and processes prevents a sole re-combination, adaptation or extrapolation of existing methods. Therefore in this paper the scientific approach of an interdisciplinary research center on engineering smart product service systems (Zentrum für das Engineering Smarter Produkt Service Systeme, ZESS) as funded at Ruhr-Universität-Bochum (Germany) is presented.
The range of Smart PSS, as described in the following section, requires a comprehensive transformation of technologies, business processes, cross-domain organizational structures, and the role of (temporarily) participating multiple actors and stakeholders. To address these challenges and to identify new ways for flexible optimization under conditions of complexity, dynamic boundary conditions and ambiguity, new methods and experimental fields must be developed in order to generate scientific knowledge that goes beyond existing case study descriptions.

2 SMART PRODUCT SERVICE SYSTEMS

In order to sustain competitive advantages and to realize high margins the focus in value creation changed from selling products to selling functionalities. This results in the need for more complex and flexible production and requires new design methods (Kowalkowski, 2010; Lenkenhoff, 2016). Especially challenging is the Business-to-Business (B2B) segment as it implies knowledge-intensive processes of integrated and combined planning, development, provision and use of products and services (Meier et al., 2010).

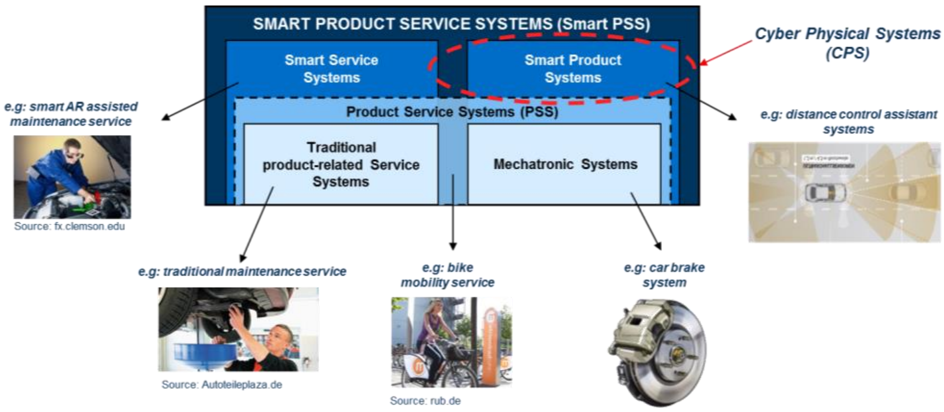

Figure 1. Classification of products and services (Abramovici et al., 2015)

Even traditional products and services are becoming smarter. The term ‘smart’ in general covers the attributes clever, intelligent, agile, modern, and intuitive. In early papers, the process of becoming 'smart' addressed mechatronic systems and traditional service systems in a separate and rather vertical manner (cf. Figure 1). Nowadays a holistic understanding predominates, Product Service Systems (PSS) describe the first level of horizontal integration.
Driven by the current ICT penetration of products and services, new opportunities arise for the horizontal integration into comprehensive smart product service systems (Smart PSS) (Monostori, 2016). Smart PSS are integrated socio-technical Product Service Systems based on networked smart product and smart service systems for providing new functionalities. One of the most popular examples is the conversion from mobile phones to smartphones. Smartphones incorporate many functions of traditional physical products like digital cameras and audio players. In addition, they integrate a multitude of IT-driven services like weather forecasts or navigation services. Other examples cover smart cars, smart factories, smart homes, or smart energy grids. These Smart PSS are defined by the following main characteristics (Abramovici, 2014; Abramovici and Herzog, 2016):

- High degree of autonomy, e.g. real-time reactivity, self-control and organization, context awareness.
- Strong human centration, e.g. high degree of personalization, easy-to-use human-machine interfaces.
- Openness and variability along the Smart PSS lifecycle, e.g. interchangeability of product or service modules and dynamic Smart PSS reconfiguration during their operation phase.
- Innovative business models, e.g. flexible cost models and new collaborative risk-sharing models which integrate the Smart PSS provider in the whole product lifecycle, in particular during the Smart PSS use phase.
- Very high degree of complexity, e.g. huge number of heterogeneous, interconnected components, strong interaction between provider and customer along the entire Smart PSS Lifecycle.

3 CHALLENGES FOR SMART ENGINEERING

Engineering lifecycles cover the "development", "manufacturing planning", "planning of product use and service provision", and "planning of reconfiguration or the end of life" for products and services. Engineering processes cover all technical activities including definition, design, documentation, simulation, and management of products and services, as well as those of related processes along the entire lifecycle. These engineering processes are supported by specific engineering methodologies and customized IT tools (e.g. Broy et al., 2010). Analyzing the availability of engineering methodologies for various products (Pahl et al, 2007) and services leads to the conclusion that, for the engineering of Smart PSS, no appropriate methodologies exist (cf. Figure 2) (Eigner et al., 2014).

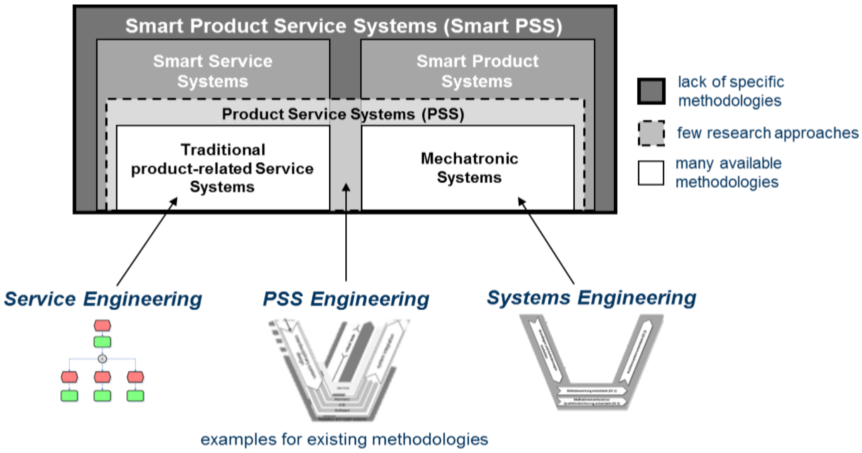

Figure 2. Availability of engineering methodologies (Abramovici et al., 2015)

Thus, the suitability of existing methodologies has to be evaluated against Smart PSS-specific engineering requirements. Based on the main characteristics of Smart PSS, the following specific requirements have been derived forming the approach presented in this paper:

- *Use of product use data and knowledge*

Smart PSS facilitate provider access to use and operational data via embedded sensors. Appropriate methods and cloud-based services for the exploitation of that data are required. The generated knowledge can be used to improve Smart PSS development processes.

- *Generic process models and methodologies*

Existing systems engineering and PSS engineering approaches have to be extended and adapted by generic processes and methodologies with focus on early engineering phases (requirement engineering, functional / architectural design, partitioning, conceptualization). In addition, engineering processes have to be flexible and definable in real-time during operation. The required methodologies have to be pragmatic and semi-formal.

- *Consideration of several design disciplines*

Engineering of Smart PSS requires the interdisciplinary collaboration of various technical, social, and business-oriented experts. Hence, there is a strong need for a holistic integration of discipline-specific models (e.g. product models, software models, service models, business models) and all involved stakeholders along the entire lifecycle, e.g. customers, partners, service providers (Guertler and Lindemann 2016).

- *Strong user focus*

Real-time decision support for users of the methodology requires assistant systems for analysis, assessment, and simulations. Furthermore, intuitive visualization and social media techniques as well as template libraries have to be implemented to ensure that the methodology is easy to use.

In line with these requirements, existing engineering methodologies have been analyzed and clustered into three classes according their engineering domain focus (cf. Figure 3).

- *System Engineering* methodologies which provide interdisciplinary approaches for the development of complex technical systems, such as document based and model based systems engineering approaches (INCOSE, 2011; Bursac et al., 2016) and a multitude of V-Model approaches (VDI, 2004).
- Methodologies focussing primarily on *Services Engineering* processes that are not necessarily related to product development processes, e.g. the service engineering concept developed by Bullinger and Schreiner (Bullinger et al., 2006) and the service design concept presented by Shostack and Kingman-Bundage (Shostack et al., 1991).
- *PSS Engineering* methodologies supporting the integrated development of industrial Product Service Systems, e.g. the property-driven development (PDD) approach (Weber et al., 2004), the extended service blueprint concept (Hara et al., 2009), the process model for PSS conceptualization proposed by Tan (Tan et al., 2009), the reference process for the integrated development of products and services by Müller and Blessing (Müller and Blessing, 2007) and the heterogeneous modelling approach for industrial product-service systems by Sadek and Köster (Sadek and Köster, 2011).

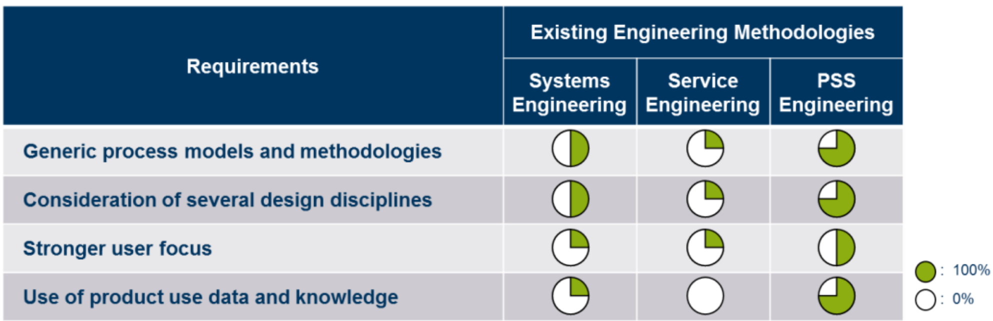

Figure 3. Suitability of existing engineering methodologies for Smart PSS

None of the existing engineering methodologies meet the presented requirements for Smart PSS Engineering sufficiently. Moreover, the analysis has shown that most specific approaches within the considered areas of methodologies focus only on product and service development. Further lifecycle phases (e.g. product operation phase in which a huge amount of sensor data can be captured and analysed for several engineering purposes) are only rarely covered by the existing methodologies. As a consequence, there is a strong need for new Smart PSS-specific engineering methodologies (Abramovici et al., 2015).

4 RESULTING RESEARCH QUESTIONS

The development of new methodologies in Smart Engineering needs to be geared to those research questions that especially arise in the context of Industry 4.0 based on cyber-physical systems (CPS). The fundamental changes for actors, processes and organizations associated with the technological changes have not been systematically investigated or systematically studied in their complex interdependencies and their interaction with technology. There is a need for comprehensive economic and social solutions by consistently reflecting provider and customer views and considering the overall lifecycle (Acatech, 2011). Neither the mere analytically driven combination of existing methodologies nor pure field study analysis do provide a sufficient basis for gaining scientific knowledge. A meta study on factors influencing engineering processes e.g. identified more than 200 context factors determining the traditional engineering process (Gericke et al., 2013). The extrapolation to engineering Smart PSS would most probably result in a multiple of additional factors. Therefore, lifecycle analysis simulations in an advanced experimental environment are most important and the only way of gaining more insights in the complex strategies of engineering Smart PSS. Moreover, a laboratory inventory is indispensable in order to generate new solutions for those obstacles firms tend to fail with in daily work.

Within laboratory tests of real-world objects and the user interaction with Smart PSS the required knowledge is gained (Tahera et al., 2014). Due to the complexity of experimentations Smart PSS simulation as a valuable research method will play an important role. In order to create and analyse specific problem situations in the lifecycle of Smart PSS, simulations will be done computer-based in virtual environments as well as with real objects and persons, e.g. simulation of sales situations with the help of test persons and product models.

Simulations and scenarios are especially useful in order to find answers to the new research questions. The following questions are derived from the requirements shown in section 2:

- *How to ensure connectivity and handle the new information overload?*

According to estimations about 100 billion objects will be connected with each other by 2020 in the Internet of Things (IoT). The connectivity provides the opportunity for companies to organize themselves in value-added clusters and to offer product related cloud services based on the use of product operation data. These new value chains achieve an unprecedented concentration on the core competence, in order to provide the necessary information-technological connectivity and an integrated management of data and processes along the entire lifecycle of Smart PSS, especially in the Smart PSS operating phase (Adelfinger, 2015).

- *How to develop interdisciplinary lifecycle engineering approaches?*

In highly competitive markets, the product and process innovation is increasingly supplemented by innovations in the fields of business models and product related IT services and, in some cases, also replaced. Traditional business models primarily address the ownership of a product. A differentiation and individualization is possible only by means of product features. On the other hand, innovative business models are often characterized by innovative profit mechanisms, which are no longer based on the expenditure. The revenue is now based on usage-related variables (e. g for manufactured parts). This results in cooperative relationships between customer and supplier, which are characterized by a close customer relationship and a long-term cooperation (Acatech, 2011)). In addition, such cooperations can be described by a joint success and risk sharing. This type of business model changes the roles of customers and suppliers. Considering these new roles the customer is no longer just the buyer of a product (Baines, 2007).

- *How to empower the multiple actors and stakeholders within the ecosystem of Smart PSS?*

There is a demand for specifying meta-competencies and related development concepts that can be applied to the multiple actors and stakeholders involved. Serious games including the different actors across domains can be considered as a new way of training that goes beyond the individual development as it addresses group development in the network of value creation (Süße et al., 2014, Bartelt, 2014). A laboratory environment and game-based infrastructure are necessary prerequisites for developing new training concepts and to measure and evaluate the realized competence development.

- *How to realize the transformation process?*

Authors understand PSS and smart systems as a new form of organizing (Süße et al., 2016), Mougaard, 2016). Especially ICT is considered with disruptive changes within and across organizations (Yoo, 2013; Kagermann, 2015). Taking social and environmental factors into consideration comprehensively to technology this type of change is often impossible. With reference to MacLean et al. (1990) and

Dertouzos (1998) one can consider the "gentle slope" approach as an alternative concept. The idea is to find ways for a gradual enhancement of complexity and skill development among the multiple actors and interactions within the ecosystem of value creation. The approach especially highlights that smart system development cannot be realized within one (big) step as it rather implies a continuous process of renewal aligned to new opportunities that can also be managed by traditional firms. In order to specify these "gentle slopes" with respect to the angle of slopes, steps of skill development, laboratory experiments with new methods and tools, e.g. for enhancing customer interaction, using big data from other domains for process development, cross-domain learning etc. are necessary.

5 DERIVED RESEARCH FIELDS

The research questions as discussed in the previous section lead to the following research fields addressing the research gaps as identified (cf. Figure 4).

- *Connectivity of Smart components*

The increasing amount of CPS initially leads to the need of new IT-security solutions. Therefore, software security is important in order to anticipate potential attacks on such systems at an early stage and to develop corresponding countermeasures. At the same time, security protocols must be analysed and improved in order to enable trustworthy communication in unsafe environments. Moreover, hardware design as related to efficient encryption methods with the smallest memory processing requirements has to be developed.

Beside the IT-security issues integrated network concepts for hardware and software systems are necessary prerequisites for a continuous link between technologies, disciplines and actors of Smart PSS.

- *Lifecycle-oriented individualization for business models and products*

The technological possibilities of connectivity will change the business models of companies in a sustainable manner. Therefore, the business model has to be considered as an active component and is subject to technological-driven changes. For this reason, a systematic development process for business models has to be developed in analogy to the product innovation process and the associated engineering lifecycle. Such a relationship leads to new interfaces, changed interactions and mutual dependencies and offers new possibilities for all stakeholders.

- *Managing complexity of interdisciplinarity in design disciplines*

A customer is involved in the complete lifecycle of the Smart PSS within the framework of participation concepts, in order to achieve an individual tailoring of its needs. Because of the novel interactions an appropriate adaption of product development, production and sales processes has to be explored. The special potential of Smart PSS could satisfy the needs of many different users and customers individually. But this results in a high degree of cross-disciplinary complexity which makes an appropriate exploration of new approaches in the area of complexity management necessary. In the context of Smart PSS, three dimensions can be described as extremely complex: the result dimension contains an extensive portfolio of individual Smart PSS, separate items and / or services. The process dimension addresses the provider's processes necessary for the creation and delivery of the service. It is characterized by the integration of the external factor as well as the enormous coordination effort within open and dynamic networks. And the potential dimension for the resources involved in the creation processes and provided for the service. The research field examines possible efforts and conditions to make Smart PSS to an active support to produce flexible and individual products. The field of tension between technology, organization and personal plays an outstanding role in customer-specific production and requires a holistic approach to related, interdisciplinary research questions. Another important aspect of today's systems is that the architecture of hierarchy is defined in line with the technical system at the time of its design. In the future, technical systems will no longer be hierarchically structured in a static way because the interdisciplinary use of such systems makes a flexible integration necessary depending on the area of application. Therefore, a statically classified component does not fully exploit the potential of smarter system components. To allow for this a new design would have to be developed as an interdisciplinary network of smart systems which is e. g. self-describing and autonomous.

- *Transformation path for providing Smart PSS*

In order to achieve value creation based on Smart PSS, companies must not only make fundamental changes at the level of business models and the necessary technological prerequisites, but also change the organization and management processes fundamentally. The transformation for providing Smart

PSS set a new user-oriented focus for companies. Management processes, decision-making systems, and organizational culture has to be restructured. The aim is to specify the transformation path in its course and the relevant inhibitors and drivers to assist companies. In case a company intends to integrate Smart PSS into its own value creation, then existing and historically developed technical, organizational as well as personnel boundary conditions must be taken into account. This is not only in the interest of the user, who integrates the Smart PSS into its value creation, but also from the suppliers point of view a critical success factor. The study of the feasibility and the progress of business transformation is another major challenge. To develop the potentials comprehensively and efficiently, new methods for the adaptation of structures, processes and framework conditions with a view to successful engineering of Smart PSS have to be investigated.

6 INTERDISCIPLINARY RESEARCH CENTER ON ENGINEERING OF SMART PRODUCT SERVICE SYSTEMS (ZESS) IN BOCHUM (GERMANY)

For deeper investigations, the specifics of the comprehensive interrelations of real and virtual components of Smart PSS and the challenges resulting therefrom, hybrid experiments with either virtual images acting in a real environment or physical objects interacting with virtual environments have to be modelled and designed. The conversion of this scientific approach into practice lead to the concept of an interdisciplinary research centre on smart engineering called "ZESS" (Zentrum für das Engineering Smarter Produkt Service Systeme). ZESS is based on four main facilities (cf. Figure 4), the "Testbed Smart PSS", the "Virtual Lifecycle Engineering Centre", the "Interaction Space" and the "Laboratory for Additive Manufacturing". In the context of a modern, representative production environment, the so called "Testbed Smart PSS", the collaboration of autonomously operating subsystems like CNC machines and mobile robotics can interoperate as well as the interaction with humans to develop appropriate assistance systems for handling Smart PSS. By extending this physical testbed into a "Virtual Lifecycle Engineering Centre" networking and communication concepts can be evaluated by applying different operating conditions on production and business model processes within the complete lifecycle.

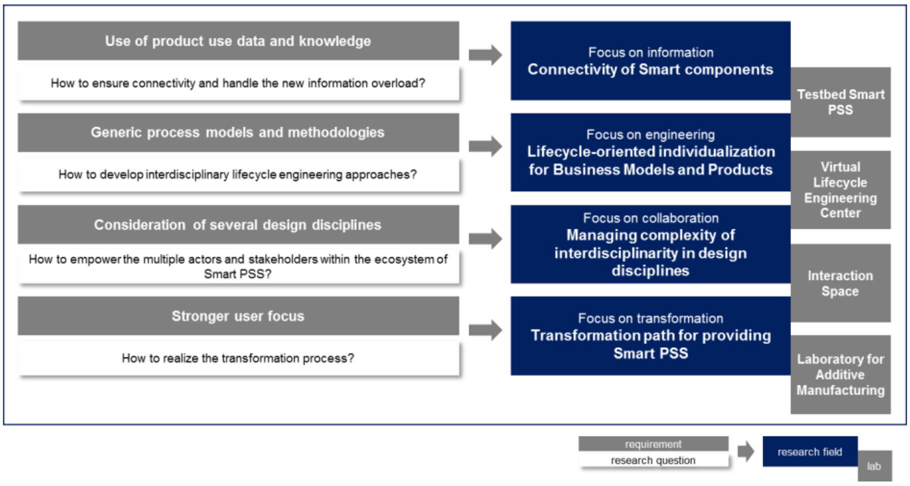

Figure 4. Research fields and included laboratories derived from the requirements of Smart PSS

In addition, a living lab approach is applied, where the integration and participation of multi actors and the new role of customers are in the focus of analysis in order to observe behaviour and interaction within an ecosystem of Smart PSS with increasing dynamic and complexity. By evaluating the interaction in the multi actor system of Smart PSS inside the so called "Interaction Space", necessary skills, e.g. for sales and service staff as well as suitable communication channels will be tested and prototyped.

The "Laboratory for Additive Manufacturing" within ZESS is designed for two important roles in Smart PSS creation and organizational transformation processes: the initial design from the technical engineering stage as well as the adoption of customer feedback from "Interaction Space" is applied to the manufacturing of Smart PSS prototypes. The second role for this lab is the representative substitute for a customer production area: even though the customer production components will be different, the selected equipment of this lab is used for showing organizational transformation processes to integrate Smart PSS. This will be achieved by upgrading, integrating and operating the 3D printers as an exemplary Smart PSS.

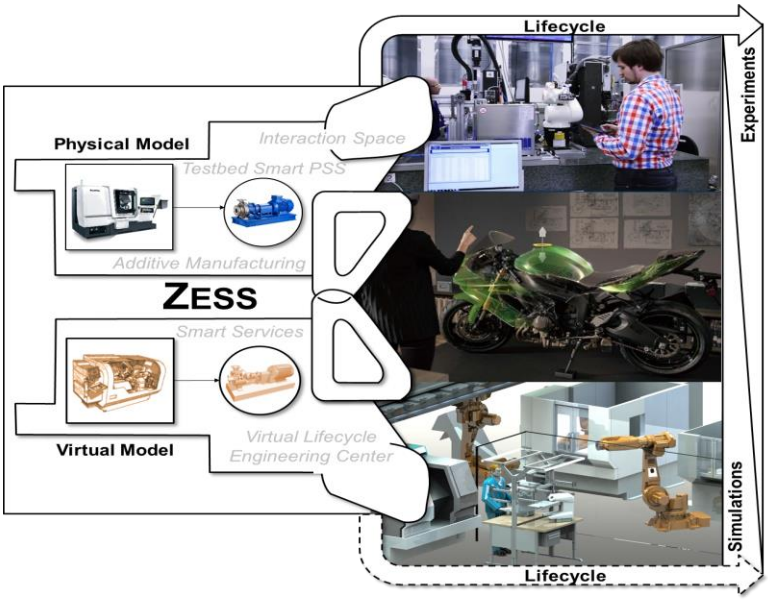

Figure 5. The interaction of research areas and infrastructure in ZESS[1]

The technical equipment to be installed in ZESS is selected for optimum conditions from research into systematic, generalized engineering approaches for a cross-sectoral product spectrum. The consideration of IT-Security and legal aspects will be integrated in the complete infrastructure. Another aspect addressed is the interconnection of all parts within the lifecycle processes of a Smart PSS. This includes for example the safe data exchange and the avoidance of data changes.

7 SUMMARY AND CONCLUSIONS

An approach to the Engineering of Smart Product Service Systems will be of disruptive nature. Dynamic boundary conditions, complex product structures, interdisciplinary cooperation networks in combination with appropriate business models must be addressed. This paper presents a research concept integrating experimental and analytical methods in close iteration loops by means of an interdisciplinary research centre. Purpose is the elaboration of a research methodology on mechanisms and methodologies to comprehensively engineer Smart Product Service Systems. As shown, current engineering methods are not sufficient for supporting an engineering process covering the whole lifecycle of Smart Product Service Systems, including design, manufacturing, business and sales models as well as their implementation and operation. The scientific concept is triggered by the lack of today's approaches in addressing cooperation in interdisciplinary networks, their inadequate suitability to integrate existing engineering methodologies (System Engineering, Services Engineering, PSS Engineering), and the absence of appropriate business models for Smart PSS.

Due to complex interdependencies of product and process conditions a purely analytic solution is not adequate to understand key context factors in this socio-technical system. Active experimentation and simulation of typical Smart PSS lifecycle situations must be integrated in developing new methodologies. This approach specifically fosters the integration of customers into all steps of the engineering process, which is again key to meeting the characteristically interdisciplinary requirements to Smart PSS.

1 Reference image (centre, right): http://www.microsoft.com/microsoft-hololense; (on top, right): http://www.lps.rub.de/tr29

REFERENCES

Abramovici, M.; Herzog, O. (Eds.) (2016), "Engineering im Umfeld von Industrie 4.0: Einschätzungen und Handlungsbedarf (acatech STUDIE)", Herbert Utz Verlag, München, ISSN 2192-6174/ISBN 978-3-8316-4501-5.

Abramovici, M., Göbel, J.C., Neges, M. (2015), "Smart Engineering as Enabler for the 4th Industrial Revolution". In: Fathi; M.(Ed.), Integrated Systems: Innovations and Applications, Springer, Berlin, ISBN: 978-3-319-15897-6.

Abramovici M. (2014), "Smart Products", In: Laperrière L, Reinhart G, (Eds.), CIRP Encyclopedia of Production Engineering, Springer, Berlin Heidelberg

Acatech (2011), "Cyber-Physical Systems. Driving force for innovation in mobility, health, energy and production (acatech POSITION PAPER)", München, Berlin, Brüssel.

Adelfinger, V. Haenisch, T. (2015), „Grundlagen: Das Internet der Dinge", In:, Internet der Dinge - Technik, Trends und Geschäftsmodelle, Springer, Wiesbaden, ISBN: 978-3-658-06728-1.

Bartelt, M.; Schyja, A.; Kuhlenkötter, B. (2014), "More than a Mockup". Production Engineering, Vol. 8, No. 6, DOI: 10.1007/s11740-014-0575-6.

Baines, T.; Lightfoot, H.; Evans, S.; et al. (2007), "State-of-the-art in product-service systems". Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Vol. 221, No. 10, DOI: 10.1243/09544054JEM858.

Baars, H.; Lasi, H. (2016), „Analytische Informationssysteme - Business Intelligence-Technologien und -Anwendungen", In: Gluchowski, P; Chamoni, P. (Eds.), Springer, Berlin Heidelberg, ISBN: 978-3-662-47762-5.

Broy, M. Feilkas, M. Herrmannsdoerfer, M. Merenda, S. et al. (2010), „Seamless Model-Based Development: From Isolated Tools to Integrated Model Engineering Environments". Proceedings of the IEEE, Vol. 98, No. 4, DOI: 10.1109/JPROC.2009.2037771.

Bullinger, H.; Schreiner, P. (2006), "Service Engineering: Ein Rahmenkonzept für die systematische Entwicklung von Dienstleistungen". In: Bullinger, H.; Scheer, A. (Hrsg.): *Service Engineering - Entwicklung und Gestaltung innovativer Dienstleistungen*. Berlin Springer, 2006 (2. Auflage), DOI: 10.1007/3-540-29473-2.

Bursac, N.; Albers, A.; Schmitt, T. (2016), "Model Based Systems Engineering in Modular Design – A Potential Analysis using Portal Type Scraper Reclaimers as an Example", Procedia CIRP, 50, DOI: 10.1016/j.procir.2016.04.156.

Dertouzos, M. L. (1998), "What will be: How the new world of information will change our lives", HarperCollins, New York, ISBN: 0-06-251479-2.

Eigner, M.; Muggeo, C.; Dickopf, T.; Faißt, K.-G. (2014), "An Approach for a Model Based Development Process of Cybertronic Systems", Proceedings of the 58th Ilmenau Scientific Colloquium, Ilmenau 2014.

Gericke, K.; Meißner, M. & Paetzold, K. (2013), "Understanding the Context of Product Development", In: *Proceedings of 19th International Conference on Engineering Design, ICED'13*. Seoul, Korea: The Design Society, Glasgow 2013, ISBN: 978-1-904670-46-9.

Guertler, M. R.; Lindemann, U. (2016), "Identifying Open Innovation Partners: A Methodology for Strategic Partner Selection". In: *Int. J. Innov. Mgt. 20 (05), S. 1640011*. DOI: 10.1142/S1363919616400119.

Hara, T.; Arai, T.; Shimomura, Y.; Sakao, T. (2009), "Service CAD system to integrate product and human activity for total value", In: *CIRP Journal of manufacturing Science and Technology 1 (2009), Nr. 4*, DOI: 10.1016/j.cirpj.2009.06.002.

INCOSE (2011), *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities* (Eds.: Haskins, M.; Krueger, K.; Forsberg, D.; Walden, R.; Hamelin, D. San Diego 2011, ISBN: 978-1-118-99940-0.

Kagermann, H. (2015), "Change Through Digitization—Value Creation in the Age of Industry 4.0", In: Albach, H., Meffert, H., Pinkwart, A., Reichwald, R., (Hrsg), *Management of Permanent Change*, Wiesbaden: Springer, 2015, DOI: 10.1007/978-3-658-05014-6_2.

Kowalkowski, C. (2010), "What does a service-dominant logic really mean for manufacturing firms?", *CIRP Journal of Manufacturing Science and Technology*, Vol. 3, No. 4, DOI: 10.1016/j.cirpj.2011.01.003.

Lenkenhoff, K.; Barthelmey, A.; Lemmerz, K.; Kuhlenkötter, B. et al. (2016), "Communication architecture for automatic plant documentation updates", *6th CIRP Conference on Assembly Technologies and Systems Vol. 44*, No. 40, DOI: 10.1016/j.procir.2016.02.100.

Meier H., Roy R., Seliger G. (2010), "Industrial product-service systems (IPS2)", CIRP Annals of Manufacturing Technology, Vol. 59, No. 2, DOI:10.1016/j.cirp.2010.05.004.

MacLean, A.; Carter, K.; Lövstran, L.; Moran, T. (1990), "User-tailorable systems: pressing the issues with buttons". *Proceedings of the SIGCHI conference on Human factors in computing systems*, New York: ACM, DOI: 10.1145/97243.97271.

Monostori, L.; Kàdàr, B.; Bauernhansl, T.; et al. (2016), "Cyber-physical systems in manufacturing", *CIRP Annals of Manufacturing Technology*, Vol. 65, No. 2, DOI: 10.1016/j.cirp.2016.04.051.,

Mougaard, K. (2016), “A framework for conceptualisation of PSS solutions: On network-based development models”, DTU Mechanical Engineering, Copenhagen.
Müller, P.; Blessing, L. (2007), "Development of Product-Service Systems - Comparison of Product and Service Development Process Models". In: *Proceedings of the 16th international conference of Engineering Design 2007*, Paris, 2007.
Pahl, Gerhard; Beitz, Wolfgang; Blessing, Luciienne; Feldhusen, Jörg; Grote, Karl-Heinrich; Wallace, Ken (Hg.) (2007), *Engineering Design. A Systematic Approach*. Third Edition. London: Springer-Verlag London Limited. DOI: 10.1007/978-1-4471-3581-4.
Sadek, T.; Köster, M. (2011), Conceptual development of Industrial Product-Service Systems. In: *Journal of Enterprise Modeling and Information Systems Architectures*, EMISA, Special Issue "Service Systems Modeling", German Informatics Society, ISSN: 1860-6059. -2011.
Shostack, L. G., Kingman-Bundage, J. (1991), "How to design a service", In: Congram, C. A. (Hrsg.); Friedman, M. L. (Hrsg.): *The AMA Handbook of Marketing for the Service Industries*. New York: Amacom, http://dx.doi.org/10.1108/EUM0000000004799.
Süße, T.; Wilkens, U. (2014), "Preparing Individuals for the Demands of PSS Work Environments through a Game-based Community Approach – Design and Evaluation of a Learning Scenario". *Procedia CIRP 2014: Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems*, Elsevier 2014, doi:10.1016/j.procir.2014.02.014.
Süße, T.; Voigt, B.-F.; Wilkens, U. (2016), “An application of Morgan’s images of organization: Combining metaphors to make sense of new organizational phenomena”. Örtenblad, A., Trehan, K. & Putnam, L. (Eds.): *Exploring Morgan’s Metaphors: Theory, Research, and Practice in Organizational Studies*, SAGE, p.111-137, 2016, ISBN-10: 1506318770.
Tan, A.; McAloone, T.; Matzen, D. 2009. Service-Oriented Strategies for Manufacturing Firms. In: Sakao, T. and Lindahl, M. (eds.) *Introduction to Product/Service-System Design*. London, Springer, DOI: 10.1007/978-1-84882-909-1
Tahera, K.; Earl, C.; Eckert, C. M. (2014), "Integrating virtual and physical testing to accelerate the engineering product development process", In: *IJITM* 13 (2/3), S. 154. DOI: 10.1504/IJITM.2014.060307.
VDI-Guideline 2206. 2004: *Entwicklungsmethodik für mechatronische Systeme*. Beuth Verlag, Berlin.
Weber, C.; Steinbach, M.; Botta, C; Deubel, T. (2004), "Modelling of product-service systems based on the PDD approach", *International Design Conference,* DESIGN 2004. Dubrovnic, Croatia, ISBN 953-6313-59-6.
Yoo, Y. (2012), "The tables have turned: how can the information systems field contribute to technology and innovation management research?” *Journal of the Association for Information Systems*, Vol. 14, No. 5, 2013, ISSN: 1536-9323.

ACKNOWLEDGMENTS

The concept and the equipment of "ZESS" presented here was acknowledged by the German Council of Science and Humanities (WR) and finally selected for funding by the Joint Science Conference (GWK) in June 2016. The federal government of Germany as well as the state government of North Rhine-Westphalia will finance half of the funding each. The authors gratefully acknowledge the funding by these two institutions for building up the infrastructure prerequisites for the future research activities and the support of all scientists involved in ZESS.